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PRODUCT IMPROVEMENT-TYPE 7029 PHOTOMULTIPLIER TUBE

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RADIO CORPORATION OF AMERICA

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WRIGHT AIR DEVELOPMENT DIVISION

NOTICES

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WRIGHT AIR DEVELOPMENT DIVISION
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FOREWORD

This report, prepared by Mr. W. K. Peifer of the Radio Corporation of America, summarizes the investigation performed under Air Force Contract AF 33(600)-38095 from November 17, 1958 to March 3, 1960, under the cognizance of The Electronic Technology Laboratory, Avionics Division, Directorate of Advanced Systems Technology, Wright Air Development Division, where it was administered under Task 41653, "Special Tubes," under Project 4156. Mr. Melvin R. St. John and B. E. Rambo served in turn as task engineers.

ABSTRACT

This report describes measurements and experiments directed to the improvement, especially with regard to stability, of the RCA 7029 photomultiplier. The development of improved stability testing procedures and the effect of varying tube design parameters are described. In additions to stability, excess low frequency noise was found to be a problem in the 7029. On the basis of these measurements a new tube type, designated the RCA D 70038 has been developed. This type has improved stability, less low frequency noise, and an envelope of improved mechanical design.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or conclusions contained herein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER:

S/
AMOS H. DICKE
Chief, Thermionics Branch
Electronic Technology Laboratory

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I. INTRODUCTION

The general objective of the work was to improve the electrical and physical characteristics of the RCA-7029 photomultiplier tube. Originally it was planned that most of the work would be directed toward the investigation and improvement of the stability characteristics of the tube. Although the 7029 was already more stable than most other commercial photomultipliers, further improvement in stability was desired to enhance its usefulness. However, during the course of the program other problems arose that were of equal importance and these were also investigated. As a result of this expanded program, the stability problem could not be investigated as thoroughly as was desired.

This report describes the design of special experimental tubes, the development of measuring equipment and techniques, and presents the stability data that were obtained. Special experimental tubes were used to investigate the various secondary emitting surfaces, the effects of various processing procedures, and the dependence of stability on operating and ambient conditions. The various secondary emitting surfaces that were investigated were Cs_3Sb, MgO, BeO, and K_3Sb. With the exception of K_3Sb, all of these surfaces are used in commercial photomultipliers. K_3Sb was investigated because it was plausible that, due to its lower vapor pressure, this material might be more stable than Cs_3Sb. In addition to the standard Cs_3Sb secondary emitting surfaces formed on nickel oxide substrates, such surfaces formed on various other substrates were also investigated. BeO and MgO were chosen as

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substrates since these are good secondary emitting surfaces themselves. MnO was used since this material used as a substrate improves the characteristics of the Cs_3Sb cathodes. Finally gold was used to obtain a relatively inert metal substrate. Also, Cs_3Sb secondary emitter surfaces that had variations in the thickness of the antimony and time of oxidization of the nickel bases were investigated. The effects on stability of aging, baking during aging, and the effects of cleaning procedures of the dynode base material were investigated in the experimental tubes. These tubes were also used to perform special tests on Cs_3Sb surfaces that were indirectly related to stability. The tests were made to obtain knowledge of the nature of fatigue.

Many tests were made in an attempt to accurately determine the stability characteristics of the 7029. First a series of tests were made to determine whether stability characteristics are reproducible or whether they are random. The data obtained from these tests indicated stability characteristics are reproducible. Tests were also made to determine how the characteristics are affected by high temperature, baking, and aging, and how the characteristics vary with different voltages and currents. However, after many of these tests were made it became apparent that sufficient time had not always been allowed for the tubes to recover after they had been operated for four or five hours. Tests were then specifically made to determine the actual recovery time of the tubes. A number of 7029's were made that had various dynode materials instead of the standard Cs_3Sb secondary emitting surfaces on nickel oxide substrates. BeO, MgO, and Cs_3Sb formed on MgO were used. These tubes were repeatedly tested for stability. Several special stability tests were made. An uncesiated photomultiplier with MgO secondary emitter surfaces

was stability tested because fatigue is often attributed to the migration of cesium. This test illustrated that cesium migration is not the major cause of fatigue. A stability test was made on a 7029 during which dynode currents as well as the anode current were measured. This was done to determine the fatigue of the individual dynodes.

This report describes the investigation of the problems that were associated with the electrical characteristics but not directly related to stability. To perform properly in its principal application, the output noise current of a 7029 in the frequency band 0.06 to 10 C.P.S. must be less than 330 uuA (peak to peak) at an anode sensitivity of 10 A/L. It was first assumed that the noise was a function of the gas pressure in the tube but this assumption was proved to be erroneous. The possibilities of the noise being caused by ion feedback, light feedback, meta-stable atoms, thermionic emission, and excess cesium were investigated. It was finally discovered that the noise was associated with the cesium content.

At the start of the program difficulty was encountered with evaporating antimony onto the cathode area. Frequently the value of light transmission rose after or even during operation of the antimony evaporation. This was eliminated by altering the processing that was done prior to the evaporation. The antimony evaporator beads that are used in the 7029 consist of pure antimony. However, some tubes were made using a platinum-antimony alloy which made it possible to outgas the tubes at higher temperatures and eliminated particles that might have been generated by the pure antimony bead.

This report also discusses the work that was done to improve the physical construction of the 7029. A modified 7029 was made that incorporated metal flanges. This design made it possible to greatly reduce the severe glass strain that was usually present in the 7029 and sometimes caused the bulbs to break after the tubes were shipped from the factory. An investigation was made to determine the optimum distance between the cathode and first dynode for best collection efficiency. But this work was impeded by poor alignment of tube components. A mounting jig was then designed to improve the alignment of the tube.

This report further describes the development of the C70038 which was designed as a replacement for the 7029. It is very similar to the 7029 but has the improvements that were indicated by the work discussed above. The major changes are the tube envelope and the dynode material. The C70038 is made with metal flanges and MgO secondary emitting surfaces which are more stable than the Cs_3Sb surfaces that were used in the 7029. Considerable difficulty was encountered in making these tubes because of the problem of low frequency noise but this was overcome by suitable processing.

For convenience in describing the work done, it is necessary to define explicitly several terms which are frequently loosely used. The stability of the 7029 is defined by the following test:

<u>Four Hour Stability Life Performance</u>

This test is performed on each 7029. Before this test is made, the tube is kept in total darkness for 24 hours. Under conditions with supply voltage E of 1000 volts, tube temperature of 25°C, the light

flux adjusted to give an anode current of 10 microamperes within one minute after turning on light source, the tube is operated for 4 hours. At the end of this period the anode current shall not increase by more than 1 microampere nor decrease by more than 1.5 microamperes. While this definition appears to be quite explicit it was found that it was not entirely satisfactory. The anode current has its maximum rate of change immediately after the light has been turned on. Consequently any variation in the time at which the anode current is adjusted to 10 uA results in a dispersion in the results of the test. To avoid this problem the light source was adjusted prior to the beginning of the dark storage period. Ideally the initial current should have been read when the light was turned on. However, the time constant of the current measuring meter prevented doing this. Hence the current was read 15 seconds after exposing the tube to the test light.

In discussing the experimental results, it is frequently simpler to speak of the inverse of stability, that is, fatigue. This term has frequently been used to describe the change in the output current of photomultipliers with constant input signal. We will use the term fatigue in this general sense. This term, however, will also be used in a specific sense. The "percentage fatigue" of a tube will mean one hundred times the ratio of the change in anode current during a four hour stability test to the initial anode current. When the anode current increases during the test, the fatigue will be called positive; when the current decreases, the fatigue will be called negative. When the distinction between these two usages is obvious from the context, the word "percentage" will be omitted.

II. STABILITY OF SECONDARY EMISSION

A. Fatigue Mechanisms

Although no detailed theoretical analysis of the basic causes of fatigue was made, a brief discussion of possible mechanisms may not be out of order. In view of the very unsatisfactory state of the basic theories of secondary emission,[1] even this can be done only in the most general terms. However, hypotheses as to the mechanism of fatigue do suggest experiments and provide assistance in thinking about and discussing experimental results.

While there are numerous references in the literature to fatigue in photomultipliers, most of the data that has been acquired pertains to a very limited number of tubes. Usually the investigators measured the characteristics of commercial tubes and had little or no knowledge of the detailed structure or previous history of their experimental tubes. Under these conditions it is not surprising that a conceptually simple hypothesis has generally been chosen to account for fatigue.

The most popular hypothesis to explain fatigue is that of cesium migration. This model has been discussed by Marshall, Coltman and Hunter[2] and by Cathey.[3] Basically this hypothesis presupposes that cesium is removed from the dynodes by electron bombardment.

1. K. I. McKay - "Secondary Electron Emission" in Advances in Electronics, Vol. I, Academic Press, New York (1940)
   H. Bruining - "Physics & Applications of Secondary Electron Emission", McGraw-Hill, N. Y. (1954)
   O. Hackenburg & W. Brauer - Fortschr. Physik 1, 439 (1954)
   R. Kollath - "Secondary Electron Emission of Solids Induced by Electron Bombardment" in Encyclopedia of Physics, Vol. 21, p.232, Springer, Berlin (1956)
   A. J. Dekker - Solid State Physics, Vol. 6, Academic Press, N. Y. (1958)
2. Fitz-Hugh Marshall and L. P. Hunter - Phys. Rev. 69, 48 (1946)
3. L. Cathey - I.R.E. Trans. on Nuc. Sci. NS-5, 109 (1958)

It is further assumed that the cesium content or coverage of the dynode surface determines the secondary emission ratio. While both of these assumptions are basically reasonable, there is no evidence that this mechanism is the controlling factor. Also, it would be rather surprising if essentially the same mechanism accounted for fatigue in such diverse materials as Cs_3Sb, Cs-AgMg, Cs-CuBe, and MgO. Since the work of W. G. Shepherd et al, [4] on pure MgO and vacuum cleaved MgO crystals of high purity definitely demonstrates the existence of fatigue in the absence of cesium, at most cesium migration can be only partially responsible for the fatigue observed in photomultipliers.

If the removal of cesium results in fatigue, then, if fatigue is measured as a function of ambient temperature, the observed variation of rate of fatigue should be determined by the activation energy of the rate determining chemical process involved. Cathey [3] gives some data on the temperature variation of fatigue. If one computes an activation energy from his data, one obtains the very low value of 0.07 e.v. This also suggests that the fatigue mechanism is more involved than the cesium migration hypothesis would suggest.

Hillert [5] has developed detailed empirical equations to describe the fatigue process. However, it is doubtful if these

3. L. Cathey - I.R.E. Trans. on Nuc. Sci. NS-5, 109 (1958)

4. W. G. Shepherd - "Study of Electrical and Physical Characteristics of Secondary Emitting Surfaces," WADC Tech. Report, 57-760, ASTIA, DOC. No. AD 155852, (1958)

5. M. Hillert - Brit. Tour App. Phys. 2, 164 (1951)

equations are sufficient to describe all forms of fatigue observed. Furthermore, these equations are of a form which could arise from numerous fundamental processes. For example, absorption-desorption processes, electrolysis, diffusion, etc. in various combinations could lead to equations of the type developed.[6]

For these reasons it is believed to be advisable to consider all possible mechanisms which might lead to fatigue and not to design experiments exclusively on the basis of existing fatigue models. Some of the possible effects which must be considered are: (1) Changes of the electron affinity of the dynode surfaces arising from adsorbed layers of cesium or other materials, development of surfaces states, diffusion or electrolysis of defects to the surface, etc., (2) Internal changes in the dynodes leading to trapping other or loss of internal secondaries. It is quite likely that the internal processes may be the more important. In the case of metals it has been shown that a change of work function by a factor of 2 leads to a change of only 60 per cent in secondary emission.[1] This same change in work function leads to a change of many orders of magnitude in thermionic emission. Also, since the secondary emitting layers on dynodes are very thin ($\sim$1000 angstroms), very small changes in the total number of impurities can markedly affect the internal electrical properties. That this is the case may be readily seen. Since the layer is of the

6. L. S. Nergaard - RCA Rev., 13, 464 (1952), has discussed diverse physical models leading to similar equations. See also: R. M. Matheson and L. S. Nergaard, Jour. App. Phys., 23, 869 (1952) and R. L. Sproull, Phys. Rev. 67, 166 (1945)

order of 500 atomic layers thick, the total number of atomic sites per cm^2 is approximately 5×10^{16}. Hence an impurity concentration of 0.1 per cent corresponds to 5×10^{13} atoms. As is well known, impurity concentrations much smaller than this often lead to enormous changes in the electrical properties of semiconductors. It is also worth noting that the total number of atoms required may be relatively small compared with the number in a monolayer ($\sim 10^{14}$).

B. Single-stage Photomultiplier Tube

1. Description:

To investigate the stability of various secondary emitter surfaces, the effects of various processing procedures, and the dependence of stability on operating and ambient conditions, a special single-stage photomultiplier tube called the C7290 was developed. A diagram of this tube is shown in Fig. 1. The tube actually contains two dynodes, one of which is used as a control dynode. The two secondary emitter surfaces lie in the same plane. One dynode is located directly above the other and separated by approximately 1/2 mm. Thus, one secondary emitter surface can be compared with another or the effect on stability of various processing procedures of the same type surface can be compared. The other electrical elements are a photocathode and a grid anode. The cathode is of the semi-cylindrical type commonly used in diode phototubes.

2. Operation:

Electrons emitted from the cathode by incident light energy pass through the grid and strike the dynodes. Secondary electrons are produced and collected by the grid which is the most positive element in the tube. By repeated tests, it was found that the number of primary electrons intercepted by the grid is not sufficient to cause a significant error in the measurements of the gain of the tube if the potential between the cathode and the grid anode is 1.5 times that between the cathode and the dynode.

3. Evaluation of Processing Procedure:

Before any stability experiments were started, tubes were made which contained different amounts of cesium to determine how much should be used to obtain reasonable gains and cathode sensitivities. Also, the exhaust procedure was varied considerably. For example, some tubes were baked, i.e., maintained at a high temperature in an oven only a short time while being pumped, and then baked for several hours after they were taken off the exhaust system. Others were baked several hours on exhaust, but then received no additional bake. From these tests, a standard procedure was established for processing the C7290.

4. Evaluation of Dynode Collection Efficiency:

Early in the program, several tubes were made with a dynode nearly equal in length to the cathode but not as wide as the

regular dynodes. Two metal strips, one placed on each side of the dynode, but not connected, were electrically connected to one of the stem leads. With such an arrangement, it was possible to estimate the collection efficiency of the dynode. It was concluded that, if the light did not strike the edge or near the edge of the cathode, the number of primary electrons that would pass by the regular size dynodes was negligible.

5. Accuracy of Gain Measurements:

To obtain useful data, it was necessary to measure the gains of these tubes with an accuracy better than one per cent. The need for such accuracy can readily be appreciated when we consider that if the gains of all stages of a photomultiplier are equal, the total gain of the tube is equal to the gain of a single-stage raised to the power of the number of stages in the tube. Therefore, a decrease of one per cent in gain of each stage in a ten-stage tube will produce a nine and one-half per cent change in the gain of the tube. In some cases, changes in gain of less than one per cent were measured during five hours continuous operation. In general, the changes in gain during such a test were very much larger. This was due to the fact that in these C7290's the maximum dynode processing temperature was restricted by the proximity of the temperature sensitive Cs_3Sb photocathode. (As will be seen later, this is not true for many standard photomultiplier tubes.) However,

this does not seriously affect the usefulness of the tube for making comparison tests.

6. Problems Encountered with the Single-stage Tube:

a. Leakage Currents:

In the original construction of the tube, two of the stem leads were used to mount the cathode. With this arrangement, the leakage path between one of the cathode supports and the anode support was less than two millimeters. The stem, which is formed of lead glass, readily absorbs cesium and its resistivity decreases. To increase this short leakage path, the cathodes were mounted on only one stem lead and a glass bead was added at the top of the tube to support the elements. While a similar spacing exists between the cathode and anode leads in this bead, the glass is of a kind which absorbs little cesium.

b. Cathode Non-uniformity:

It was generally found that the sensitivity of the cathode varied from top to bottom. Usually, the bottom of the cathode had higher sensitivity than the top. An attempt was made to correct this situation by adding a second cesium generator near the top of the tube (the first tubes had only one generator). It appeared that slightly better uniformity was achieved with this change, but it was obviously not a complete solution of the problem. Since the lower portion of the cathode is heated more strongly during the operation of sealing the stem into the bulb,

this process was modified. Some improvement was made by performing the sealing operation more rapidly, but most of the cathodes had some non-uniformity.

c. Variation in Stability Between Top and Bottom Dynode:

Some tubes were made in which both dynodes had Cs_3Sb secondary emitter surface. In most of these, the bottom dynode was more stable than the top, although in some, it was just the opposite. It was thought that perhaps the temperature differential as discussed above was responsible for this. Also, there was the possibility that the hot gases from the sealing process contaminated the top dynode. Therefore, tubes were made with a small tubulation at the top of the bulb which allowed these gases to escape during scaling. This tubulation was closed after the sealing process. No improvement was observed when this was done.

7. Preliminary Tests:

a. Test of Method:

Early in the program, a tube was made with Cs_3Sb dynodes. One of these dynodes was oxidized before it was coated with antimony and the other was left unoxidized. Fig. 2 shows the dynode currents as a function of time. Current readings were taken with a potentiometric voltmeter which will be discussed later. It was expected that the unoxidized dynode would fatigue more than the oxidized. The purpose of the test was to check the usefulness of the tube and the reliability of the test equipment.

Since the curves fit the points of the graph quite well, it was assumed that this method of measurement was satisfactory. The potential between cathode and dynode for this test was 90 volts and the potential betwen the cathode and anode was 135 volts. This voltage was used for most tests since the 7029 is normally operated at 90 volts per stage.

b. Reproducibility of Stability Characteristics:

Stability data of a tube with one MgO and one Cs_3Sb secondary emitter surface is shown in Fig. 3. The results of two tests are shown. The second test was made two days after the first. The smooth curves were drawn to best fit the points obtained from the first test. It is obvious that the points from the second test fit the curves quite well. The data was taken with an ultrasensitive microammeter. If the potentiometric voltmeter had been used, the points would undoubtedly fit the curves even better.

C. **Test Equipment**

1. Single-stage Photomultiplier Test Equipment:

Fig. 4 shows the device that was constructed to test the stabilities of the single-stage photomultipliers. Three of these units were used. As previously mentioned, it was necessary to measure changes in gain of less than one per cent. Thus, the stability of the lamp had to be better than one per cent. A light source with such stability will be described later.

The cathode and dynode currents were obtained by measuring the voltages across the resistors with a potentiometric DC voltmeter (Model 801, John Fluke Mfg. Co., Inc., Seattle, Washington). These resistors are mounted between binding posts on the outside of the light-tight box. A partition with a shutter mechanism is located between the tube and the lamp. With this partition, the lamp may be connected to the storage battery and allowed to stabilize before the test is started. (The first test unit that was used did not have this partition and was not satisfactory since the intensity of the lamp changed during the first few minutes of operation.) By adjusting the aperture size and position of the tube with respect to the aperture, it was possible to keep the light energy off the edges of the cathode. However, the light intensity was not great enough to obtain high primary current densities in the tubes. Therefore, some tests were made during which the cathode was flooded with light from two 60-watt tungsten lamps. In this case, no resistors were used - the currents were measured directly with a microammeter. The light intensity could be changed by changing the voltage across the lamps with a variac. Thus, to insure that the primary current densities were the same each time that the dynode currents were measured during a stability test, it was only necessary to adjust the lamp voltage so that the cathode current reading was the same. This latter method was found satisfactory for stability tests of tubes in which the two secondary emitter surfaces were to be compared.

2. <u>7029 Test Equipment</u>

Figure 5 shows the schematic drawing of the test rack used to check the stability of the 7029 photomultiplier tube. This equipment was originally

designed to test another tube type. For the original use, two power supplies were needed. For the 7029 test, special socket adapters were constructed and a stable light source was provided. The light source, which is identical to the one used in the single-stage multiplier test set, will be discussed later. Five tubes can be tested simultaneously with the equipment. Each tube is placed in a separate compartment which has its own iris and shutter mechanism. The compartments are arranged so that a single lamp can supply light energy to all five tubes. This is a definite advantage since only the stability of one lamp needs to be checked. However, filters must be used if all five tubes are to operate in the same current range because of the large variation of sensitivity from tube to tube. At first, Wratten neutral density filters were used, but later polaroid filters were installed which could quickly be adjusted to obtain the desired light intensity for each tube. A separate bleeder was provided for each tube.

Small changes in the output supply E_2 were detected by measuring the voltage drop across a section of the bleeder with the potentiometric voltmeter previously mentioned. Small changes in output voltage of the supply E_1 were detected by measuring the difference between the voltage drop across a section of the bleeder and a "bucking voltage" provided by batteries. The meter (V_1) that was used for this measurement is a Model WV-98A,

RCA Senior Voltohmyst. During the program, the 15 megohm potentiometer had to be changed several times because it became "noisy" and accurate measurements could not be made. For this reason, the use of the bucking voltage was discontinued and the potentiometric voltmeter was also used to measure the changes in E_1. By making such measurements, it was possible to adjust the output voltages of the two supplies so that the overall voltage across the tubes did not vary by more than ± 0.5 volts when the current readings were made.

3. Light Sources

To detect changes in gain of one per cent or less in the single-stage photomultiplier, it is necessary that the light intensity vary by less than one per cent. Standard lamps were first considered as a possible stable light source. However, it is difficult to obtain a sufficiently constant current to operate such a lamp. Moreover, the intensity would have to be greatly decreased by filters or spherical mirrors and this would increase the complexity of the equipment. It was, therefore, decided that a two volt lamp operated from a storage battery would be tried.

The stability of such a lamp is extremely difficult to measure. Changes in intensity were detected by using a diode phototube. Since it was impossible to see a change of one per cent on the microammeter used to measure the photocurrent, a "constant current generator", approximated by a series of batteries and a high series impedance, was used to oppose the photocurrent and the

difference current was then measured. Thus, a change in photocurrent could readily be detected. Figure 6 shows the circuit arrangement used for this test. The current in the lamp circuit was determined from measurements made with the potentiometric voltmeter. There were two disadvantages of this method: (1) The diode phototube might not have been stable; (2) The small batteries used to provide the "opposing current" might not have been stable.

To eliminate problem (2) above, the voltage drop across a series resistor in the lamp circuit was checked with the potentiometric voltmeter. The circuit is shown in Fig. 7. Simultaneously, the battery terminal voltage and the voltage across a rheostat in the lamp circuit were measured.

In several instances, rather sudden changes in lamp current and in light output occurred without a corresponding change in the other quantity. While these events cannot be definitely explained, repeated tests indicate that these were probably due to poor contacts in the metering circuits. Whenever deliberate small changes of lamp current have been made, corresponding changes in light output have been observed. Prolonged and repeated tests have lead us to the conclusion that, provided sufficient time is allowed for the battery to stabilize after switching on, the light output of this source varies less than 0.2 per cent in a four-hour period.

The light source that is presently used in the multiplier tube test rack and also in the single-stage multiplier test set is shown in Fig. 8. The potential across the lamp is measured with the differential voltmeter and periodically adjusted to its original value. If such a change is made every hour, the change in light output for a four-hour test period will be less than 0.1 per cent.

Changes in battery voltage and lamp output as a result of temperature changes were investigated and it was found that they were negligible for a temperature change of several degrees C.

A six volt lamp was used successfully in the single-stage multiplier test set.

D. Experiments Performed with the Single-stage Photomultiplier Tube

1. Stability of Various Secondary Emitter Surfaces:

a. Introduction:

Single-stage tubes were made for measuring the stability characteristics of Cs_3Sb, MgO, BeO, and K_3Sb secondary emitter surfaces. In some tubes, both dynodes were the same; in others, two different surfaces were compared. Not much work was done during the early part of the program with MgO and BeO since dynodes with these surfaces must have a higher potential applied to them to get a gain equal to that of Cs_3Sb. Thus, these surfaces could

not be used in the 7029 unless the maximum voltage rating of the tube were exceeded. During the course of the contract, we were informed that the voltage could be increased in the application of the tube. Therefore, more consideration was then given to these materials. K_3Sb was investigated as a secondary emitter surface. It was not expected that the gain of this type surface would be as high as that of Cs_3Sb, but it was thought that it might be high enough to be used in the 7029 and that it might be more stable because its vapor pressure is lower. The results, however, indicated that the gain is much too low.

b. Stability of MgO and Cs_3Sb Secondary Emitter Surfaces in Single-stage Tube:

(1) <u>Procedure:</u>

The dynode base material for the Cs_3Sb secondary emitter surface was nickel. This nickel was oxidized so that the actual substrate was nickel oxide. The nickel oxide was then coated with antimony. The dynode base material for the MgO secondary emitter surface was a silver-magnesium alloy. This was oxidized to form a layer of MgO. One dynode of each type was assembled in each tube. The tubes were exhausted and outgassed. Cesium vapor was then admitted to the tube. The tube

was heated and the cesium reacted with the antimony to form cesium antimonide. The tubes were then aged and secondary emission measurements were made.

(2) Preparation of Cs_3Sb Substrates:

The nickel parts were degreased in trichlorethylene at about 75°C and then rinsed in deionized water. After drying, these parts were sealed in a glass tube and pumped down to three microns pressure. The tube was then placed in a furnace and the parts were outgassed at 880°C for 15 minutes. Oxygen was then admitted to a pressure nearly equal to atmospheric pressure. One minute after the oxygen was admitted, the tube was removed from the furnace and quickly cooled. The parts were removed from the tube.

(3) Antimony Evaporation:

Antimony was evaporated onto the nickel parts in a bell jar. The pressure during evaporation was less than 1 micron of Hg.

(4) Preparation of MgO Surfaces:

The AgMg alloy base material for the MgO surfaces was cleaned as follows: The parts were first washed in trichlorethylene to remove all grease. The parts were washed in ether, then boiled in a 10% solution of acetic acid for 15 minutes. They were then rinsed in deionized water. They were washed in acetone and finally dried in

in an oven at 110°C. The parts were oxidized as follows: They were put in a long, hard glass bulb about 4 inches in diameter. The open end of the bulb was connected to an exhaust system by a plastic tube. A small amount of water was then put in the cold trap of the system and frozen by a mixture of methanol and dry ice in the flask around the trap. The pressure was reduced to about 1.5 microns Hg. The glass tube was placed in an electric furnace at about 550°C for 10 minutes. During this time, the water vapor from the ice in the trap reacted with AgMg to form a layer of MgO on the parts. At the end of the 10 minutes, the bulb was removed from the oven, cooled, and opened to air at atmospheric pressure The bulb was then flushed with oxygen. The bulb was again put in the furnace, this time at 725°C. Oxygen was forced through the bulb at a rate of 10 liter/minute for 15 minutes. The bulb was then removed from the furnace, cooled, and the parts were removed.

(5) Construction:

Single-stage tubes were assembled with one AgMg dynode and one Cs_3Sb dynode. The cathode base material was nickel. It was cleaned and coated with antimony the same as bases for the Cs_3Sb secondary emitter surfaces. Thus, during processing, a Cs_3Sb photosurface was formed.

(6) Exhaust Procedure:

The tubes were pumped down to 10^{-5} mm Hg. They were then outgassed for 2 hours at 240°C. After cooling, the cesium generator was heated by RF induction and cesium condensed on the inside bulb wall. Each generator contained a mixture of two parts silicon and one part cesium chromate by weight. The total weight in each was 35 mg. When heated, the silicon reacted with the chromate and free cesium was liberated. The tubes were then closed off from the pumps and baked at 160°C for one-half hour. During the bake, the cesium reacted with the antimony on the dynodes and cathodes to form Cs_3Sb. Undoubtedly, some cesium also reacted with or was absorbed by the MgO to form a composite surface. (MgO-Cs.) Pumping was then started and the tubes were baked an additional 70 minutes at 170°C to remove excess cesium. After cooling to room temperature, the tubes were sealed off from the exhaust system.

(7) Aging and Testing:

The tubes were aged, that is, operated for 1/2 hour. Forty-five volts was applied between the cathode and dynodes and anodes. (The dynodes and anodes were connected electrically.) The currents ranged between 30 and 35 μa. One day after aging the tubes were tested for gain. Ninety volts was applied between the

cathode and dynodes. Forty-five volts was applied between the dynodes and anode. As previously mentioned, it had been determined that the potential between the cathode and anode should be 1.5 times that of the potential between cathode and dynodes.

(8) Stability Tests:

These tubes were stability tested three times. The first two tests were made with the same voltages as above, i.e., 90 and 45 volts. After the first test, the tubes were baked at 155°C for 35 minutes. They were then aged for 15 hours, again at 90 volts and 45 volts. Three days after aging, they were tested the second time. One week after the second test, they were tested the third time. This time, the voltages were 115 and 57 volts.

(9) Test Results:

Figures 9 and 10 show the results of the three tests for tube No. 54 and Figures 11 and 12 show the results for tube No. 55. The initial readings of the tests were taken between 45 and 60 seconds after voltage was applied and the tubes were exposed to light. The values obtained for the gains in the initial test after processing are shown below. Also, the initial and final dynode currents are shown for the 15 hour aging period.

Tube No.	54	55
Gain		
AgMg dynode	2.1	2.1
Cs_3Sb dynode	3.9	4.3
Dynode Currents (aging)		
Initial		
AgMg dynode	12	13
Cs_3Sb dynode	30	23
Final		
AgMg dynode	10	8
Cs_3Sb dynode	13	10

In tube No. 54, the AgMg dynode was at the top position and the Cs_3Sb at the bottom. In tube No. 55, they were just reversed. As can be seen from the graphs, the baking and aging caused increased fatigue for the Cs_3Sb dynodes. In tube No. 55, the current of the AgMg dynode increased steadily during the stability test before the bake, but after the bake, it increased only for about the first half-hour and then decreased. However, the rate of increase was greater after the bake so that the percentage of positive fatigue was actually greater during the latter test. In tube No. 54, the AgMg dynode had no positive fatigue before the bake and this process did not affect the characteristics significantly although there was slight positive fatigue after the bake.

The characteristics from the third test for the Cs_3Sb dynodes at 115 volts are nearly identical to those of the second test at 90 volts. Also, the characteristics of the AgMg for the third test are similar to those of the second.

c. Stability of MgO in the Single-stage Tube

(1) Procedure:

Most of the single-stage tubes that were made had Cs_3Sb photocathodes. Thus the tubes could not be baked at temperatures as high as desired since the photosurface would be destroyed. However, a small number of tubes was made using Ag-O-Cs cathodes and these could be baked at higher temperatures than those with the Cs_3Sb cathodes. Near the end of the program two tubes with AgMg dynodes were made with such cathodes. (12 other tubes were made also with this type cathode.- each tube had one CuBe (BeO surface) and one AgMg (MgO surface) dynode. These will be discussed later.) The MgO surfaces were prepared the same as those in the preceding section. The cathode base material in this case was silver. After assembly, the tubes were exhausted, outgassed, and activated. They were then aged and tested.

(2) Exhaust Procedure:

The tubes were pumped down to about 10^{-5} mm Hg. They were then outgassed for $1\frac{1}{2}$ hours at 360°C. During the last 15 minutes of this bake, oxygen was admitted to a pressure of about 10 mm Hg so that any contaminants remaining on the dynode would be burned off. After the tubes were pumped down and cooled, oxygen was again admitted and the cathodes were oxidized by a glow

discharge between the cathode and grid. This glow discharge probably affected the dynodes little, if any. The tubes were again pumped down and cesium was admitted. Each tube contained one generator with 45 mg of cesium chromate and silicon in a 2:1 ratio. The tubes were then baked at 230°C for 15 minutes.

(3) Aging:

The tubes were aged about 24 hours with 90 volts applied to the dynodes in normal room illumination. Dynode currents were about 1 microampers.

(4) Test Results:

The gains of these tubes were measured and the tubes were then stability tested with 90 volts between the cathode and dynodes. Initial readings for the stability tests were taken 30 seconds after voltage was applied and the tubes were exposed to light. Five days after the first stability test, another stability test was made but this time the cathode-to-dynode potential was 115 volts. The stability characteristic curves for these tests are shown in Figs. 13 and 14. Prior to making stability tests, the gains of the tube shown in Fig. 13 were - top dynode - 3.1, bottom dynode - 3.0. The gain for the tube shown in Fig. 14 were - top - 2.8, bottom - 2.9. For one tube (Fig. 14) we see that the characteristics of both dynodes

at 90 and 115 volts are similar but that the fatigue at 115 volts is considerably less than at 90 volts. For the other tube, however, the characteristics for the different voltages are quite different. At 90 volts, both dynodes fatigue positively, while at 115 volts, both have considerable negative fatigue. One would not expect this difference since both tubes were processed in the same fashion and at the same time.

d. Stability of BeO and Cs Sb Secondary Emitter Surfaces in the Single-stage Tube

(1) Procedure:

These tubes were made using nearly the same procedure that was used for those with MgO and Cs_3Sb secondary emitter surfaces. (Section IIIDlb) However, more cesium was used in these and the tubes had to be baked longer to remove the excess. Also, the BeO surfaces were not prepared in the same manner as the MgO surfaces.

(2) Preparation of the BeO Surfaces:

The CuBe alloy base material for the BeO surfaces was cleaned as follows: The parts were first cleaned in trichlorethylene to remove all grease. The parts were washed in ether and then washed in a solution of 50% acetic acid and 50% hydrochloric acid. They were then rinsed in the deionized water. Finally, they were rinsed in acetone and dried in air. The parts were oxidized in water vapor the same as the AgMg parts but

they were not flushed with oxygen at a high temperature like the AgMg parts.

(3) Exhaust:

The tubes were pumped down to 10^{-5} mm Hg and outgassed for $1\frac{1}{2}$ hours at 240°C. After cooling, cesium was admitted to the tubes. Each generator contained a total of 50 mg of cesium chromate and silicon. As before, the tubes were closed off from the pumps and baked at 160°C for $\frac{1}{2}$ hour. Then, while being pumped, they were baked nearly 2 hours at 170°C. The cathode sensitivities and leakage currents were measured during this bake. This length of time was necessary to reduce the leakage currents, caused by excess cesium, to reasonable values. Obviously, less cesium should have been used. (Note - These tubes were made before those with the MgO and Cs Sb surfaces and those were then made with less cesium.)

(4) Aging and Testing:

The tubes were aged for $\frac{1}{2}$ hour with 45 volts applied between the cathode and the dynodes and anode. The currents ranged between 30 and 35 microamperes. Several days after aging, the gains of the tubes were measured. The voltages for the tests were 90 and 45.

(5) Stability Tests:

The procedure followed for stability testing was the same as

for the tubes with the MgO and Cs_3Sb dynodes. The first two tests were made at 90 and 45 volts. Between these tests, the tubes were baked at 155°C for 35 minutes and then aged for 15 hours again at 90 and 45 volts. The second test was performed three days after aging. One week after the second test, they were tested the third time at 115 and 57 volts.

(6) Test Results:

Figs. 15 and 16 show the results of the three tests for tube #49 and Figs. 17 and 18 show the results for tube #50. The initial readings of the tests were taken between 45 and 60 seconds after voltages were applied and the tubes were exposed to light. The values obtained for the gains in the initial test after processing are shown below. Also, the initial and final dynode currents are shown for the 15 hours aging period.

Tube No.	49	50
Gain		
CuBe dynode	2.2	2.0
Cs_3Sb dynode	4.1	3.0
Dynode Currents (aging)		
Initial		
CuBe dynode	8.5	11
Cs_3Sb dynode	16	20
Final		
CuBe dynode	9	7
Cs_3Sb dynode	9	12

In tube #49, the CuBe dynode was at the top position and the Cs_3Sb at the bottom. In tube #50, they were just reversed.

Fig. 19 shows the stability characteristics of a third tube with a BeO and Cs_3Sb secondary emitter surface. This tube, with one exception, was processed the same as discussed above, though at an earlier date. The length of the final bake for this tube on exhaust was one hour. This was sufficient to reduce the leakage although the amount of cesium in this tube was the same as for those above. In this particular case, the curves obtained from plotting dynode currents against time are almost identical to those in Fig. 19. The dynode currents were of the order of 0.1 microampere and the potential between cathode and dynodes was 90 volts. The gain of the Cs_3Sb dynode at 90 volts was 4.4 and of the CuBe was 2.4 (prior to stability testing).

As before, the effect of the bake on the Cs_3Sb dynodes was to increase the fatigue although the change for tube #50 was not very significant. The effect of the bake on the CuBe dynodes was to change the characteristics from positive to negative fatigue.

At 115 volts, all the dynodes had increased negative fatigue but the changes were small except for the Cs_3Sb dynode in tube #49 where the increase was rather large. The characteristics

of tube #38 at low current are similar except that the Cs_3Sb dynode current does not drop immediately.

e. Stability of BeO Secondary Emitter Surfaces in a Single-stage Tube

(1) <u>Procedure:</u>

A series of five stability tests were made on a tube with two BeO secondary emitter surfaces. The BeO surfaces were prepared the same as those in the preceding section. The tube also contained the same amount of cesium. However, the activation bake was slightly different. The tube was baked two hours at 170°C. During the first thirty minutes, the tube was closed off from the exhaust system.

(2) <u>Aging:</u>

Again, the initial aging was the same as that for the tubes in the preceding section. Between the fourth and fifth stability tests, the tube was again aged for about 60 hours. For this aging 50 volts was applied to the top dynode, 100 to the bottom. The anode potential was 150 volts. The initial top dynode current was 1.9 microamperes. The initial bottom dynode current was 2.7 microamperes.

(3) <u>Testing:</u>

Several days after the initial aging, the gains were measured at 90 volts. The gain of the top dynode was 2.8, bottom 2.5. Three days after the gain measurements, the first stability test was made. About one month after the first test, the second

test was made and the third two weeks after the second. The data for these first three tests are plotted in Fig. 20. The fourth test was made eleven days after the third and the fifth one week after the fourth (four days after aging). The data for the last two tests are plotted in Fig. 21. All these tests were made at 90 volts. The dynode currents for the first two tests were roughly 0.05 microamperes. The dynode currents for the third, fourth, and fifth tests were respectively about 0.3, 0.5, and 0.7 microamperes. The characteristics for the first two tests are nearly the same, as they should be, since the test conditions were the same. At higher currents, the bottom dynode, which was previously more stable, changed more due to an initial sharp decrease. The baking and aging process eliminated this decrease and also decreased the slope of the positive fatigue. The bake caused the top dynode to increase sharply for the first few minutes and then decrease slowly thereafter. The result was that both dynodes became more stable. But the top which was aged at only 50 volts was considerably more stable than the bottom.

f. Comparison of Stability Characteristics of MgO and BeO Secondary Emitter Surfaces

(1) Procedure:

Twelve tubes were made with one CuBe dynode and one AgMg dynode. These were made to determine which secondary emitter

surface was the most stable. However, the cathodes (which were Ag-O-Cs photosurfaces) had very low sensitivities and it was not possible to operate the tubes at high dynode currents. The BeO surfaces were formed the same as those described in Sec. IIDld. The MgO surfaces were formed the same as those described in Sec. IIDlb.

(2) Exhaust Procedure:

The tubes were processed similarly to those in Sec. IIDlb. The tubes were pumped down and when a pressure of about 10^{-5} mm Hg was reached, they were baked for one hour at 200°C. The temperature was then increased to 360°C and baked two hours. During the last 15 minutes of this bake, oxygen was admitted to a pressure of about 10 mm Hg. After the tubes were pumped down and cooled, oxygen was again admitted and the cathodes were oxidized by a glow discharge between the cathode and grid. The tubes were again pumped down and cesium was admitted. Each tube contained one generator which had a mixture of two parts silicon and one part cesium chromate by weight. Total weight was 45 mg. The tubes were then closed off from the pumps and baked for 15 minutes at 175°C. Pumping was again started and the temperature was raised to 250°C and held for one hour. Apparently, the cathodes sensitivities would have been higher if the tube had not been baked so long. However, the

leakage would then have been too high to accurately measure the dynode currents. The tubes were cooled and tipped off from the system. The final pressure was about 10^{-6} mm Hg.

(3) Aging:

The tubes were aged 24 hours with 90 volts between the cathode and dynodes and 45 volts between dynodes and anode. The dynode currents ranged between 1 and 4 microamperes.

(4) Test Results:

Three weeks after aging, the tubes were stability tested. The voltages were 90 and 45. The data were plotted and the curves are shown in Figs. 22 to 32. Dynode currents ranged between 1.0 and 3.5 microamperes. The initial readings were taken one minute after the tubes were exposed to light.

The gains of the dynodes are given below. These were measured at 90 volts.

Tube No.	CuBe Secondary Emitter Surface	AgMg Secondary Emitter Surface
1	2.9	2.8
2	3.3	3.2
3	2.8	3.1
4	2.9	2.9
5	2.8	2.9
6	3.3	3.0
7	2.8	3.1
8	3.4	3.4
9	3.7	3.2
10	3.2	3.1
11	3.0	3.0

The characteristics as shown in Figs. 22-32 should not be considered as being very accurate. As previously mentioned, the cathode sensitivities were very low and this made it difficult to obtain reliable data. For example, it is doubtful that the currents of a dynode would increase, then decrease and again increase as is seen in Figs. 31 and 32. This is probably due to experimental error. However, the results, along with the results previously obtained, indicate that the characteristics of the two materials are similar. But one must remember that different processing techniques or different operating procedures, could produce quite different results.

g. Stability of K_3Sb Secondary Emitter Surfaces in the Single-stage Tube

(1) Procedure:

A number of tubes were made in which potassium was used instead of cesium. It was not expected that the gain of the secondary emitter surfaces would be as high as if cesium were used. However, it was thought that the gain might be comparable to that of MgO and BeO, but more stable. In the first three tubes, the potassium reacted with the lead in the glass stem and none was available to react with the antimony. Three more tubes were then made with stems formed from a lead-free glass but these stems had only two lead wires. These had only one dynode and it was supported by a lead wire that

was sealed in the top of the bulb. The secondary emitter substrates were formed and the antimony evaporation was performed the same as in Sec. IID1b.

(2) Exhaust:

The three tubes were exhausted individually. The first tube was pumped down to 10^{-5} mm Hg. It was then outgassed at 240°C for 2 hours. After cooling, a generator was heated and potassium was released in the tube. The generator contained, by weight, one part potassium chromate, one part aluminum, and eight parts tungsten. The total weight of the mixture was approximately 95 milligrams. The tube was then closed off from the system and baked at 185°C. After baking 25 minutes, no photosensitivity was observed so potassium was released from the second generator. (The tube was pumped while potassium was being released.) The tube was cooled and removed from the exhaust system.

(3) Aging:

The tube was operated for three hours with 90 volts between cathode and dynodes and 135 between cathode and anode. The dynode current was about 4 microamperes.

(4) Stability Test:

The tube was tested for 7 hours with 90 volts between cathode and dynode. The primary curent was about 26 microamperes (about 15 microamperes per cm^2). These data are plotted in Fig. 33. The fatigue is less than 5%. A second stability

test was made at the same voltage but lower current. The primary current was about 7.2 microamperes. During six hours, the fatigue was less than 2%. The gain of the dynode, however is only about 2. A curve of gain versus voltage is shown in Fig. 34 for this tube. Apparently the value obtained for 500 volts was not correct.

(5) Exhaust and Testing of Other Two Tubes:

The other two tubes were exhausted in the same manner with the following exception: Both generators were "flashed" initially and, after flashing, one was baked 2 hours and the other $1\frac{1}{2}$ hours. The baking time was determined by the photoemission and leakage. The gains of these were less than two. The photoemission of one was very low and it was not stability tested. The other showed 7% positive fatigue during a five hour test at 90 volts. The primary current was about 9 microamperes. The results obtained indicate that this type secondary emitter surface is very stable. However, the gains were too low to be of practical utility. Again, different processing might have yielded higher gains but to investigate the problem completely would have required more time than was considered justifiable under this program. It is interesting to note that the secondary yield reaches a maximum at only two hundred volts and drops very little up to 800 volts. (Leakage currents were too large to obtain data at higher voltages). The yield of Cs_3Sb surfaces, on the

other hand, reaches a maximum at 500-600 volts and the curve is not nearly so flat in the vicinity of the maximum.

2. Variations in Oxidization and Antimony Thickness of Cs_3Sb Dynodes:

a. Procedure:

Tubes were made which had two Cs_3Sb secondary emitter surfaces. One of each pair of surfaces had some variation in the thickness of antimony or the oxidation time of the nickel base. The other was a standard surface, i.e., it was processed the same as the Cs_3Sb surface previously described. Twelve tubes contained dynodes on which the antimony was about two-thirds the normal thickness. Previous to the evaporation, the nickel bases of four of these were oxidized one minute as discussed in Sec. IID1b(2). Four were oxidized one-half minute and four two minutes. Eleven contained dynodes on which the antimony was about twice the normal thickness. The time of oxidization on these was as follows: Three dynodes - 1 minute, four dynodes - 3/4 minute, four dynodes - 2 minutes. In addition seven tubes had surfaces with the standard antimony layer but four of these were oxidized for 3/4 minute and three for two minutes. Some of these tubes had an orifice, or small tubulation at the top of the bulb which was sealed after the mount was sealed in the bulb. However, as previously stated, this did not appear to effect the stability characteristics.

b. Processing:

Some of these tubes were pre-exhausted, i.e., they were evacuated

and then sealed without processing. The tubes of course, had to be exposed to air when they were again sealed to the exhaust system. These tubes were #3, 4, 7, 8, 11, 12 and 24 thru 30. These tubes were exhausted the same as those in Sec. IID1b. Each tube contained two 50 mg cesium generators. All of these tubes were aged about three days with cathode to dynode potential of 90 volts. The cathode currents were between 5 and 15 microamperes.

c. Stability Tests:

All tubes were tested with a potential of 90 volts between cathode and dynode and 45 volts between dynode and anode. These test data are listed in Table #1, p.41. The percent fatigue of each dynode and the initial dynode currents for the stability test are shown. The oxidization time and the thickness of the antimony layer as compared with the standard layer are given for each experimental dynode. Also the position in the tube of each experimental dynode is given. Not all the tubes were tested exactly the same length of time. However, this does not affect the results when one dynode is compared with the other. Moreover, if one tube is compared with another, the effect of this difference in test time is quite small since the change in gain after the first three hours is small. The time for each test, in general, was about four hours. It was not expected that the dispersion in the data would be as great as it is. There are large differences in the stabilities of two dynodes in one tube as well as between two tubes. The most one can conclude is that these

Table No. 1

Comparison of Standard Cs Sb Dynode and Cs Sb Dynodes with Variations in Antimony Thickness and Oxidization Time

	Experimental Dynode					Standard Dynode	
Tube #	Position△	Oxidization Time	Antimony✧ Thickness	% Fatigue	Initial* Current	% Fatigue	Initial Current
1	B	½ (Min.)	2/3 X	17	.82 ua	11	1.84
2	T	½	"	17	1.38	15	1.18
3	B	½	"	9	.46	12	.47
4	T	½	"	25	.99	16	1.03
5	B	1	"	15	.87	11	1.22
6	T	1	"	15	1.77	19	1.65
7	T	1	"	17	1.24	26	1.42
8	B	1	"	20	.88	18	1.10
9	T	2	"	4	1.13	7	1.15
10	B	2	"	12	1.43	16	1.29
11	T	2	"	25	.89	29	.82
12	B	2	"	34	.82	19	.90
13	T	3/4	1½ X	27	1.11	21	.53
14	T	"	"	7	.53	12	.77
15	B	"	"	17	1.15	10	.77
16	B	"	"	6	1.87	11	1.60
17	T	1	"	3	1.47	6	1.89
18	T	1	"	12	.45	10	.501
19	B	1	"	15	.75	19	1.07
20	T	2	"	10	.42	9	.36
21	T	2	"	7	1.22	16	1.28
22	B	2	"	16	.50	25	.63
23	B	2	"	4	.51	<1	.45
24	T	3/4	1	5	.47	12	.60
25	B	3/4	"	16	.52	9	.58
26	B	3/4	"	12	.27	<1	.42
27	T	2	"	10	.42	14	.48
28	B	2	"	17	.37	13	.51
29	T	2	"	9	.67	19	.59
30	T	2	"	17	.66	24	.94

△ Indicates whether the experimental dynode was at the top (T) or bottom (B) position in the tube.

✧ Thickness of layer as compared with thickness for standard surface.

* Initial dynode current for stability test.

variations in antimony thicknesses probably do not affect stability, but if primary currents are considered, one might expect to get slightly better results by increasing the time of oxidization. Since this large dispersion was obtained, it can be concluded that it probably would have been better to investigate these two problems separately, i.e., determine first whether stability is dependent upon the oxidization and then experiment with variation in antimony thickness. Moreover, variations should also have been made in the pressure during oxidization. However, the program covered so many aspects that limits had to be set on the thoroughness of the investigation of any one of them.

3. Cs_3Sb Secondary Emitter Surfaces Formed on Various Substrates:

a. Introduction:

As previously mentioned, the standard Cs_3Sb surfaces are formed on nickel bases. The nickel is oxidized so that the actual substrate is nickel oxide. To determine whether the substrate has any affect on the characteristics of secondary emission, Cs_3Sb surfaces were made on four different types of substrates. BeO and MgO were chosen since these are good secondary emitter surfaces themselves. MnO was used since this appears to improve the characteristics of Cs_3Sb cathodes. Finally gold was used to obtain a relatively inert

metal substrate. Single-stage tubes were made that had one dynode which was made with a special substrate and a standard dynode with the nickel oxide substrate for comparison. A number of surfaces were made with each of the different substrates. Some were used for the top dynode and some for the bottom dynode of the single-stage tube so that one could be certain that the position of the surface did not affect the results.

b. Cs_3Sb Secondary Emitter Surfaces Formed on MnO Substrates:

(1) General:

Twelve single-stage tubes were made in two groups of six each. Each tube contained one Cs_3Sb secondary emitter surface formed on a MnO substrate. The photo- and secondary-emitter surfaces in all the tubes of the first group were destroyed when the exhaust system failed.

(2) Formation of Substrates:

The MnO substrates were formed on nickel bases. These nickel parts were degreased in trichlorethelene at about 75°C and rinsed in deionized water. They were then cleaned in the following solution at 75°C: acetic acid - 60% (by volume), nitric acid - 40%, hydrochloric acid - 0.005%. The parts were again rinsed in deionized water and then electroplated using a platinum anode and the following electrolyte: Hydrated manganous sulfate - 75 grams/liter, ammonium sulfate - 13 grams/liter, citric acid - 1 gram/liter,

hydroxylamine sulfate - ½ gram/liter. The magnanese that was plated on the parts oxidized as soon as it was exposed to air. The parts were again rinsed in water, then in acetone and dried in air. The nickel oxide substrates for the standard dynodes were prepared in the same manner as those in Sec. IID1b.

(3) Processing:

These tubes were processed in the same manner as those in Sec. IID1b. Each tube contained two 50 mg cesium generators.

(4) Test Results:

The gains of all the dynodes were measured and are shown in Table #2.

Table No. 2

Comparison of Cs_3Sb Secondary Emitter Surfaces on Nickel Oxide and on Manganese Oxide

	Nickel Oxide			Manganese Oxide			
Tube #	Gain	% Fatigue ✓	I_D*	Gain	% Fatigue	I_D	Position ✱
1	4.3	43	2.3	3.8	8	2.0	T
2	4.2	43	2.0	4.0	24	2.2	B
3	4.5	28	2.0	3.7	11	2.0	B
4	4.2	49	1.4	3.3	31	2.4	T
5	4.0	30	1.7	3.5	51	2.5	B
5-retest		46	7.4		14	10.4	
6	3.9	59	6.4	3.5	33	9.5	T

✓ Percent fatigue of dynode current from four hour stability test with cathode to dynode potential equal to 90 volts and constant primary current. All fatigue is negative.

I_D* Initial dynode current of four hour stability test.

✱ Indicates whether dynode with MnO substrate is in the top (T) or bottom (B) position in the single-stage tube.

After this first test, the tubes were aged for 24 hours. Initial dynode curents ranged between 8 and 12 micro-amperes. Two weeks after aging, the stability tests were started. All testing and aging was done with a cathode to anode potential of 90 volts. The per cent fatigue from the four hour stability test and the initial dynode currents of the test are also shown in Table #2. Also, the position of the dynode in the tube is indicated in the table. The equipment was not functioning properly when tube #5 was stability tested. Therefore, this tube was retested at a later date. From the table, it is seen that in every case the dynode with the MnO substrate is more stable than the standard dynode. However, the gains of these are also less than those of the standard dynodes but they are high enough to be useful in the 7029.

c. Cs_3Sb Secondary Emitter Surfaces Formed on MgO Substrates

(1) General:

Twenty-four single-stage mounts with a Cs_3Sb secondary emitter surface formed on MgO substrates were made in two groups of twelve. In six of the first group the antimony later on the MgO was of standard thickness, i.e., it was the same thickness as is normally used on the standard Cs_3Sb dynodes. For the other six the antimony layer was very thin. Only enough antimony was evaporated onto these so that the appearance of the surface was

nearly the same as a pure evaporated antimony surface. Four tubes of this first group were broken during the process of sealing the mount into the bulb and sealing the tubes to the exhaust system. For the second group, several thicknesses of antimony were used. The thickness was determined by observing the decrease of light transmission during the evaporation. However, all the tubes of this group were scrapped because they were heated to too high a temperature during exhaust and the secondary emitter surfaces were destroyed. The experiment was not repeated because of lack of time.

(2) Formation of Substrates:

The MgO surfaces were formed the same as those in Sec. IID1b. The following procedure was used to form the nickel oxide. The nickel base material was cleaned in trichlorethylene at about 75°C as before. However, these parts (nickel) did not have the same appearance as the ones that were used before. Thus, they were cleaned ultrasonically in a commercial detergent called "Tergitol". The nickel parts were then oxidized the same as those in Sec. IID1b. To be sure that there were no significant impurities present, this oxide layer was removed by heating the parts in hydrogen for 10 minutes at 800°C. The parts were then oxidized again in the same manner.

(3) Processing:

The parts were coated with antimony as before except that the layer on some of the MgO surfaces was made very thin as mentioned. Again, the tubes were exhausted the same as those in Sec. IID1b.

(4) Test Results:

The gains of all the dynodes were measured and are shown in Table #3. After this first test the tubes were aged for 48 hours. One week after aging, the stability tests were started. All testing and aging was done with a cathode to anode potential of 90 volts. The per cent fatigue from the four hour stability test and the initial dynode currents of the test are also shown in Table #3. The position of the dynode in the tube is indicated in the table.

Table No. 3

Comparison of Cs Sb Secondary Emitter Surfaces on Nickel Oxide and on Manganese Oxide

	Nickel Oxide			Magnesium Oxide			
Tube #	Gain	% Fatigue	I_D*	Gain	% Fatigue	I_D	Position*
			Standard Antimony Layer				
1	3.0	40	0.9	3.3	24	1.6	B
2	2.8	38	0.8	4.1	30	2.0	B
3	2.6	49	3.5	4.2	40	8.2	B
4	3.0	40	1.0	4.1	16	1.5	T

Table No. 3 (Cont'd.)

Tube #	Nickel Oxide Gain	% Fatigue	I_{D*}	Magnesium Oxide Gain	% Fatigue	I_D	Position
			Thin Antimony Layer				
5	2.7	42	0.7	4.0	9	1.8	B
6	2.9	38	0.9	3.6	8	1.9	B
7	3.5	40	1.3	3.2	3	1.4	T
8	2.7	45	4.4	3.9	10	10.0	B

Per cent fatigue of dynode current from four hour stability test with cathode to dynode potential equal to 90 volts and constant primary current. All fatigue is negative.

I_{D*} Initial dynode current of four hour stability test.

Indicates whether dynode with MgO substrate is in the top (T) or bottom (B) position in the single-stage tube.

We see that the gains of the standard surfaces are rather low while the others are comparable to standard surfaces that were made previously. Apparently, the base material did contain contaminants which were not removed or hydrogen was absorbed which affected the secondary emitter surface. At any rate, it can be concluded that the substrate is very important for gain. More important, however, is the fact that the fatigue of those surfaces with the thin layer of antimony on MgO is considerably less than the others. Such surfaces may be a solution to the stability problem.

d. Cs_3Sb Secondary Emitter Surfaces Formed on BeO Substrates

(1) General:

Six single-stage mounts were made with Cs_3Sb secondary emitter

surfaces formed on BeO substrates. The thickness of the antimony layer on the BeO was measured by light transmission. For three of these surfaces, antimony was evaporated until the light transmission decreased by 53%. For the other three, the light transmission decreased by 88%. One tube from each group was lost during sealing.

(2) Formation of Substrates:

The CuBe base material was cleaned and the BeO surfaces were formed according to the procedure that was used in Sec. IID1d.

(3) Processing:

Again, the tubes were processed like those in Sec. IID1b.

(4) Test Results:

The gains of all the dynodes were measured and are shown in Table #4, p-50. After this test, the tubes were aged for 24 hours. Four weeks after aging, the stability tests were started. All testing and aging was done with a cathode to anode potential of 90 volts. The per cent fatigue for the five hour stability test and the initial dynode currents of the test are also shown in Table #4. The position of the dynodes in the tube and the per cent decrease in light transmission for evaporations are indicated.

Here, as with Cs_3Sb on MgO, We see that the fatigue is smaller for the thin surfaces formed on BeO. Apparently the thickness of antimony is critical - we see that the two surfaces with

Table No. 4

Comparison of Cs_3Sb Secondary Emitter Surfaces on Nickel Oxide and on Beryllium Oxide

	Nickel Oxide			Beryllium Oxide				
Tube #	Gain	% Fatigue ⁄	I_{D*}	Gain	% Fatigue	I_D	Position ✱	% Trans. #
1	3.3	50	7.0	4.4	19	7.0	B	88
2	3.8	12	8.5	3.4	3	7.3	B	53
3	3.8	27	8.6	3.9	1	7.0	B	53
4	3.9	45	8.6	3.4	16	7.4	T	88

⁄ Per cent fatigue of dynode current from four hour stability test with cathode to dynode potential equal to 90 volts and constant primary current. All fatigue is negative.

I_{D*} Initial dynode current of four hour stability test.

✱ Indicates whether dynode with BeO substrate is in the top (T) or bottom (B) position in the single-stage tube.

Decrease in light transmission during antimony evaporation

the thinnest layers are the more stable. However, to definitely establish this, more tubes would have to be made since this is a rather small sample. Two explanations could be given for this increased stability in the case of the thin layers of antimony on MgO and BeO. First, it could be a function of the thickness of the Cs_3Sb surface directly. (The antimony layer in those experiments on the standard nickel oxide substrates was much thicker than here.) Second, some of the secondary electrons may originate in the oxide layer which was seen to be more stable than the Cs_3Sb. Stability characteristics of a multiplier made with Cs_3Sb secondary emitter surfaces on MgO strongly indicate that this does happen. This will be discussed later. However, neither of these explanations account for the fact that the

standard thickness of Cs_3Sb on MnO is apparently more stable than those on nickel oxide.

e. Cs_3Sb Secondary Emitter Surfaces on Gold Substrates

(1) General:

Eleven tubes were made. Each tube had one dynode with a regular nickel oxide substrate and one dynode with a gold substrate. The gold substrates were electroplated onto nickel bases. The substrates were prepared identically except that one group (B) of five had a plating current of 0.2 amps whereas the others had 0.4 amps (Group A). Also one dynode from each group was mechanically brushed after electroplating to check the adherence of the gold.

(2) Formation of Substrates:

The nickel bases for the gold substrates were degreased in trichlorethylene at about 75°C and then rinsed in deionized water. They were then dipped in a 50% solution of HCl at 70°-80°C for 5 seconds followed by a water rinse. The parts were next given a nickel strike, i.e., they were plated electrolytically with nickel at a high current density. This was done to increase the adherence of the gold. The electrolyte used for the plating was nickelous chloride - 22.1 oz/gal, hydrogen chloride - 1.175 l/gal. After the nickel plating, the parts were again rinsed in water. The parts were then gold plated in an electrolyte which consisted of the following - sodium gold cyanide 1.4 av. oz./gal, potassium cyanide 1.5 av. oz./gal, and disodium phosphate 1.0 av. oz./gal. After the plating, the parts were again rinsed in water, then in

acetone. The nickel bases for the regular dynodes were degreased in trichlorethylene at about 75°C and then immersed in an acid solution which had the same composition as that used in Sec. IID3b(2). The nickel was oxidized in the standard manner.

(3) Processing Procedure:

Antimony was evaporated onto the parts according to standard procedure.

(4) Test Results:

The gain of all the dynodes were measured and are shown in Table #5.

Table No. 5

Comparison of Cs_3Sb Secondary Emitter Surfaces on Nickel Oxide and on Gold Substrates

	Nickel Oxide			Gold			
Tube #	Gain	% Fatigue ✓	I_D*	Gain	% Fatigue	I_D	Position ✱
1 °	4.3	51	9.6	4.0	38	8.8	T
2	4.4	41	9.6	3.7	33	6.6	T
3	3.9	10	9.3	3.5	16	6.4	T
4	4.1	49	8.1	3.5	44	6.6	B
5	4.2	19	8.1	3.5	27	6.6	B
6	4.2	41	9.7	3.7	42	8.5	B
7 °	4.0	55	7.7	3.6	31	8.5	T
8	4.0	53	9.6	2.2	6	3.1	T
9	4.6	55	7.5	2.3	+9	2.3	T
10	3.8	39	8.2	2.4	+6	3.2	B
11	4.5	41	7.5	1.8	+11	1.8	B

° The gold substrates for these dynodes were mechanically brushed.

✓ Per cent fatigue of dynode current from four hour stability test with cathode to dynode potential equal to 90 volts and constant primary current. All fatigue is negative except where indicated by (+).

* Initial dynode current of four hour stability test.

✱ Indicates whether dynode with gold substrate is in the top (T) or bottom (B) position in the single-stage multiplier tube.

After this first test the tubes were aged for 29 hours. Four days after the aging ended, the stability tests were started. The per cent fatigue from a four hour stability test and the initial dynode currents of the test are shown in Table #5. The position of the dynode in the tube is also indicated as top (T) and bottom (B). All testing and aging was done with 90 volts between the cathode and dynode. Tubes #1-6 are group A and #7-11 are group B. As previously mentioned the plating current for group A was twice that for group B. With the exception of #7, all the dynodes of group B are considerably more stable than those of group A and the standard dynode. However, the gain of these is very low. It is interesting to note that #7, which was mechanically brushed had characteristics similar to those of group A. The characteristics of group A are similar to the standard dynodes. Actually the Cs Sb surface was not formed on a pure gold surface, because it was seen that during processing the gold partially diffused into the nickel.

4. Variations in Processing Cs_3Sb Dynodes:

a. Aging:

(1) Introduction:

A number of experiments were conducted to determine whether stability can be improved by aging. Most of these, at some phase or other, were performed concurrently since it was not possible to complete one experiment before starting the next.

(2) **Aging at Different Voltages:**

(a) Procedure

Eight tubes with Cs_3Sb dynodes were tested at different voltages to determine whether aging affects stability. The secondary emitter surfaces were prepared the same as those in Sec. IID1b. Each tube had two 50 mg cesium generators. Also, the tubes were exhausted according to the procedure given in Sec. IID1b except for slight difference for four tubes. These differences are as follows: For Tube #33 and 34 the outgassing period was only 1½ hours and during the entire activation bake the temperature was 170°C. For tube #40 the activation bake was 15 min. longer than usual. For tube #50, outgassing was at 240° for 1½ hours and the activation bake was 160°C for ½ hour and then 170°C for nearly 2 hours.

(b) Aging and Testing

Tube #33 and #34

After exhaust the gains of these tubes were as follows:

Tube #	Top Dynode	Bottom Dynode
33	3.8	3.7
34	4.2	4.0

The tubes were then aged for 2 hours with 45 volts between the cathode and dynodes. The anode was at the same potential as the dynodes. The cathode currents were about

60 microamperes. Next, the tubes were aged for about 24 hours with only 27 volts between the cathode and dynode, and at low currents (roughly several microamperes). About two weeks after aging, the gains were checked again and found to be as follows:

Tube #	Top	Bottom
33	4.2	4.4
34	4.5	4.6

Several months later, the tubes were stability tested at 90 volts. The dynode currents for #33 and #34 were respectively about 2 μa and 1 μa. The fatigue was as follows:

Tube #	Top	Bottom
33	20%	12%
34	20%	19%

The tubes were then aged as follows for about 60 hours. For #33 the potentials were - cathode to bottom dynode = 50 volts, cathode to top dynode = 100 volts, cathode to anode = 150 volts. The primary dynode currents ranged between 5 and 10 microamperes. For tube #34 the potentials were -- cathode to bottom dynode = 100 volts, cathode to top dynode = 50, and cathode to anode = 150. Again the primary dynode currents were between 5 and 10 microamperes. Three days after aging, these tubes were again stability tested with the following results:

Tube #	Top	Bottom
33	14%	4%
34	13%	6%

Tube #34 was then aged again but this time the bottom dynode was at 50 volts and the top at 100 volts. Primary dynode currents were about 3 microamperes. The tube was aged about 60 hours. About one week after aging, the tube was again stability tested with the following results:

Top	Bottom
8%	3%

Tube #40 was first aged for $\frac{1}{2}$ hour with the dynode and anode 45 volts positive with respect to the cathode. The cathode current was about 30 microamperes. After this the tube was aged about 40 hours at lower currents (several microamperes) with only 27 volts applied. One week after aging, the gains of the dynodes were measured. The gain of the top dynode was 3.6. The gain of the bottom dynode was 2.6. Several months after testing, the tube was stability tested at 90 volts. During $4\frac{1}{2}$ hours, the bottom dynode current fatigued 26% and the top 27%. However, the initial gains were - top dynode - 4.1, bottom - 3.4. This is a considerable increase in gain from the time that the tube was first tested. The tube was then aged at 90 volts for three days with dynode currents of about 10 microamperes. Three days after

aging another stability test was made (90 volts). During five hours the bottom dynode current fatigued 29% and the top 34%. Dynode currents were about ½ microampere.

The gains of tube #'s 83, 84, 85, 86 after exhaust but before any aging were as follows:

Tube #	Top	Bottom
83	3.5	3.7
84	4.3	4.2
85	3.3	3.9
86	4.2	3.7

The tubes were then aged as follows:

#83 2 days at 45 volts with dynode currents about 7 microamperes, cathode to dynode potential was 45 volts.

#84 Same as 83

#85 Top dynode was aged at 45 volts (27 volts between dynode and anode) but the bottom was aged at 90 volts (45 volts between dynode and anode). However, the two were not aged simultaneously. While the top was aged, the bottom was disconnected electrically and vice versa. Both were aged two days. Initial dynode currents were about 7 microamperes.

#86 Same procedure as for #85. Initial dynode currents about 10 microamperes.

These four tubes were stability tested at 90 volts for four hours except #86 which was tested for 4½ hours.

Stability test results:

Tube #	Top Dynode Fatigue	Bottom Dynode Fatigue
83	21%	18%
84	12	24
85	5	13
86	16	14

Dynode currents during the stability test were about $\frac{1}{2}$ microampere except in the case of #84 the current was about 1 microampere.

Tube #45 was first aged for $\frac{1}{2}$ hour with the cathode current about 30 microamps. 45 volts were applied between the cathode and dynode, the anode was electrically tied to the dynode. It was next aged for about 80 hours at 27 volts with a cathode current of several microamperes. The tube was then baked for $\frac{1}{2}$ hour at $150^{\circ}C$. The gain at 90 volts was then: top dynode - 4.0, bottom - 3.0. About 2 months later, the tube was stability tested and the following results were obtained: top dynode fatigue - 20%, bottom dynode fatigue - 9%, initial top dynode current 1.6 ua, initial bottom dynode current 1.1 ua. The initial gain for this test was top 4.6, bottom 3.6. The tube was then aged at 90 volts with dynode currents about 10 microamperes for 3 days. Two days after aging, the tube was again stability tested. This time both initial dynode currents were about 1.5 microamperes. The fatigue was as follows: top dynode 28%, bottom 31%.

It was known that Cs_3Sb dynodes fatigue from bombardment even if they are not operated as a secondary emitter, i.e., if the dynodes are used as collectors. A series of tests were made on this tube to determine how the fatigue

caused by this bombardment correlates with the fatigue that results from normal operation. For the first test - the dynodes were bombarded with electrons of 90 ev energy for four hours. Primary current for the bottom dynode was 0.23 ua. Primary current for the top dynode was 0.30 ua. Just prior to bombarding, and immediately after, the tube was briefly operated as a multiplier and the dynode currents were measured. Before bombarding, the bottom dynode current was .76 ua and the top 1.08. After bombarding, the bottom was .64 and top .90. Fifteen hours after the bombardment the tube was operated with the same cathode current. Now the dynode currents were: top .57 and bottom .78. During the first 30 minutes of operation the currents rose to .59 and .80 and then decreased thereafter. One would not expect that the gain would decrease after bombarding ceased as it did here. However, this effect also occurs in the 7029. This will be discussed later.

Other tests were made at these low current and voltages but the accuracy of the results are questionable. Tests were then made in which higher currents were used. First, the dynodes were bombarded with electrons of 11 ev energy. The bombarding current to bottom dynode was 3.3 ua. The bombarding current to top dynode was 5.9 ua. Just prior to bombarding the gains were: top 5.0, bottom 3.8.

Immediately after bombarding the gains were: top 4.8, bottom 3.7. Two days later, the dynodes were bombarded by electrons of 8 ev energy. The top dynode bombarding current was 6.0 ua and the bottom dynode bombarding current was 10 ua. However, no change in gain was observed as a result of this bombardment. One day later, the tube was operated as a multiplier with a primary electron energy of 8 ev for 3 hours. The gain at this voltage was less than unity initially but the final gain was greater than unity. This was acertained by observing that the current in the dynode circuit changed from a positive to negative polarity. The change in gain, however, was very small and a similar change caused by bombardment could not be detected since in this case the secondary emission was measured at 90 volts before and after bombardment.

The tube was also bombarded and operated normally at 23 volts and 47 volts. The bombarding current at 47 volts was: top 5.0 ua, and bottom 10 ua. Bombarding time was 3 hours. For normal operation, the top dynode current decreased from 23.5 ua to 15 ua. The bottom decreased from 19 to 14 ua. Operation time was $3\frac{1}{2}$ hours. For bombarding, the top dynode current decreased from 22.5 to 20 and the bottom from 19 to 16.5 ua. Similar results were obtained for 23 volts. However at 90 volts,

the decrease caused by bombarding was the same as that caused by normal operation. In each case the top dynode current decreased from 24 to 14 and the bottom from 19 to 13. The time of bombardment and of normal operation was 3 hours each. The bombarding currents were top 8 ua, bottom 6 ua.

(3) Time and Current Density Experiment:

(a) Procedure

Six tubes were made with Cs_3Sb dynodes to determine whether the aging of these surfaces is a function of total current or whether it depends on current density. However, considering the variations obtained in the data discussed thus far, one should not rely too much on data obtained from only six tubes. But as stated before, experiments such as this had to be started before results were obtained from the others.

(b) Processing Procedure

The secondary emitter surfaces were prepared the same as those in Section IIDlb. Also the regular exhaust procedure was followed (Sec. IIDlb). However, the activation bake at 170°C was 1½ hours instead of only 1 hour. Again, the tubes had two 50 mg generators.

(c) Aging and Testing

All the tubes were aged at 90 volts for 2½ hours with

cathode currents between 0.5 and 1.0 ua. The gains were then measured and were as follows:

Tube #	Top Dynode	Bottom
1	3.5	3.9
2	4.2	4.1
3	4.1	3.8
4	4.3	4.2
5	3.4	3.3
6	4.0	3.4

Tubes #2, 4, 5, and 6 were then aged for 20 days with cathode currents between 0.5 and 1 ua.

Tubes #1 and 3 were aged 26 hours. Initial dynode currents were:

Tube #	Top	Bottom
1	8	10
3	7	7

About one month after aging, the tubes were stability tested for 4 hours. The test results are given below:

	Top Dynode		Bottom Dynode	
No.	Fatigue	Initial Current	Fatigue	Initial Current
1	34%	1.7	40	1.9
2	30	1.9	31	1.8
3	35	1.9	37	2.0
4	32	1.7	36	2.3
5	42	1.9	41	1.6
6	41	1.8	43	1.8

Tubes #1 and 3 were then aged 16 more hours at 90 v. The initial dynode currents were about 10 ua. Three weeks later, these tubes were again stability tested, but at higher currents.

	Top Dynode		Bottom Dynode	
No.	Fatigue	Initial Current	Fatigue	Initial Current
1	47%	5.8	51	7.1
3	41	6.3	49	7.1

(4) **Heating During Aging:**

(a) Procedure

Six tubes were made to determine how stability is affected if the tubes are heated while they are aged. Each tube contained two 50 mg cesium generators. The Cs_3Sb surfaces were prepared in the same manner as those in Sec. IID1b. Also, the tubes were exhausted the same as those in Sec. IID1b.

(b) Testing and Aging

The tubes were aged 7 hours at 90 volts. The initial dynode currents were about 10 ua. One week after aging the gains of the tubes were measured.

Tube #	Top Dynode	Bottom Dynode
1	3.9	4.1
2	4.1	4.1
3	4.6	5.0
4	4.6	4.5
5	5.1	4.7
6	4.2	4.1

Tubes #1, 2, and 3 were then placed in an oven with a light source and operated at 90 volts for 60 hours (at room temperature). The initial and final dynode currents are given below:

	Top dynode		Bottom Dynode	
No.	Initial	Final	Initial	Final
1	27	11	31	10
2	48	17	54	17
3	36	10	44	12

This decrease was not all due to fatigue. The intensity

of the lamp decreased.

At the end of the aging, tube #105 was removed from the oven and the other two were baked at 100°C for ½ hour. One week later, these tubes were stability tested for 4 hours at 90 volts. The initial dynode currents were between 1 and 7 ua.

Tube #	Top Dynode Fatigue	Bottom Dynode Fatigue
1	21%	26%
2	25	29
3	11	19

The tubes were then again aged for three days at 90 volts. The primary dynode currents were between 3.5 and 6.2 ua. After three days the tubes were again stability tested for 4 hours at 90 volts.

Tube #	Top Dynode Fatigue	Bottom Dynode Fatigue
1	18%	21%
2	26	30
3	12	17

The same procedure was started for the other three tubes but an electrical short occurred while the tubes were being aged in the oven. And this time the current was not checked prior to baking - the short was discovered after baking so it was not known whether these tubes had fatigued.

(5) Tubes Aged on Exhaust:

Six tubes with Cs Sb dynodes were made to age on exhaust. That is, the tubes were procssed in the usual manner, but before they were removed from the pumps, the tubes were aged. However, the gains of these tubes were very low. It was then discovered that there was a deposit of some sort on the inside bulb wall. Apparently, when the cesium generators were heated, the cathode and dynodes also got hot and antimony evaporated from their surfaces.

b. **Cleaning of Cs Sb Secondary Emitter Substrates:**

Eight tubes were made to check different methods of cleaning the nickel base material for Cs_3Sb substrates. Each tube had one dynode that was degreased in trichlorethylene and then cleaned in an acid solution as discussed in Sec. IID3b: acetic acid - 60% (by volume), nitric acid - 40%, hydrochloric acid - 0.005%. These were then outgassed and oxidized as in Sec. IID1b. These dynodes will be designated by C. Four tubes had dynodes that were first cleaned ultrasonically in detergent, then cleaned in trichlorethylene, then outgassed and oxidized. This oxide was then removed by heating in hydrogen to 800°C for ten minutes. The parts were then outgassed and oxidized. These parts will be designated by A. The other four tubes had dynodes that were cleaned like those in Sec. IID1b, i.e., they were degreased in trichlorethylene, then outgassed and oxidized. Each tube contained two 50 mg cesium generators. The tubes were processed the same as those in Sec. IID1b. The gains of these tubes were as follows:

Tube #	Top Dynode	Bottom Dynode
1	3.2 A	3.2 C
2	3.9 A	3.7 C
5	3.6 B	3.7 C
6	3.6 B	3.8 C
7	3.9 C	3.4 B
8	3.8 C	3.6 B

(one tube was broken - another had very low sensitivity)

The tubes were then aged 17 hours at 90 volts. The initial dynode currents were about 20 ua. Seven weeks after aging the tubes were

stability tested. The per cent fatigue and initial dynode currents are given below:

1	54%	8.0 ua	56%	10 ua
2	47	9.6	50	11.4
5	49	7.8	45	9.5
6	51	8.7	53	10.2
7	43	9.3	44	9.6
8	38	8.2	51	9.4

The fatigue for all these was greater than would be expected. However, the indication is that there is no difference in stability due to the different cleaning methods.

5. Special Test of Cs_3Sb Secondary Emitter Surfaces:

a. Introduction:

Special single-stage tubes were made to perform several experiments. These tubes had two holes in the cathode, one hole directly opposite the center of each dynode. Each hole was 1/8" in diameter. The light loss through these holes was not sufficient to cause any problem during normal operation. However, this made it possible to direct light onto the dynodes and measure the photoemission of these surfaces. With these tubes spectral response data were obtained of the dynode surface before and after aging, secondary emission and photoemission were simultaneously measured, and gain versus voltage data were taken before and after aging. The Cs_3Sb secondary emitter surfaces were prepared the same as those in Sec. IID1b and the exhaust procedure used in that section was followed for these tubes. The tubes were aged for about 2 hours at 90 volts. The cathode currents were about 1 ua. The gains of these tubes were then measured: Tube # 60 - top 4.2, bottom - 5.0, tube # 62 - bottom 3.7, (negligible gain on top dynode of this tube).

b. Spectral Response:

The spectral response of the four dynodes in tubes #60 and #62 was measured. The tubes were then aged for 2 days at 90 volts. The initial dynode currents for #60 were about 2 ua. The initial dynode currents for #62 were about 2.5 ua. Spectral response data was then taken immediately after aging. These data were plotted and are shown in Fig. 35 to 38. The fatigue in gain from aging is shown in the figures. The fatigue for #60 was much less than for #62 and we see that there was less change in the spectral response curve for #60.

c. Decrease in Photoelectric Emission of a Cs_3Sb Surface as a Result of Fatigue in Secondary Emission:

Simultaneous measurements of photoemission and secondary emission were made of the bottom dynode in tube #62. The tube was operated at 90 volts as a multiplier for about 8 hours. During this time, photoemission of the dynode was measured a number of times by briefly illuminating the dynode with a second light source behind the cathode. The light passed through the hole in the cathode. These data are shown in Fig. 39. The initial dynode current was 1.3 ua. The initial photocurrent was 1.2 ua. It is seen that the photoemission decreases with the secondary emission fatigue.

d. Gain vs. Volts Before and After Fatigue:

Gain versus volts data was taken for the bottom dynode of tube #62. This was done both before and immediately after aging for 12 hours at 100 volts. The initial dynode current for aging was

5.7 ua. This data is shown in Fig. 40. It appears that the peak of the curve after aging has shifted slightly to higher voltages.

6. Stability Characteristics at Low Temperatures:

Tube #34 which was previously discussed (Sec. IID4a) was stability tested at -24°C. This test was for 5½ hours at 90 volts. The initial dynode currents were about 12 ua. The tube and light source were both placed in a large cold box. The data of this test are shown in Fig. 41. The tube was kept at this low temperature after the stability test and the recovery of the dynodes was checked. This information is given below. The first row of figures gives the final gains of the 5½ hour test.

Time	Gain of Top Dynode	Gain of Bottom
0	3.3	3.6
1 hr.	3.7	3.4
10 hr.	3.9	3.4
17½ hr.	3.9	3.4
Temperature increased to room temp. at 17½ hr.		
18½ hr.	4.2	3.4
40	4.4	3.6

Several days later, the tube was again stability tested at room temperature and recovery data was also taken. The initial dynode currents, however were higher (top - 24.5, bottom - 21.0). These are plotted in Fig. 42 It is seen that the recovery is much more rapid.

E. Stability of the 7029

1. Introduction:

Stability tests were made on 7029's to determine (1) whether stability characteristics of these tubes are reproducible, (2) how the characteristics

are affected by high temperature, and (3) how the characteristics vary with different voltages and currents. As previously mentioned, five 7029's could be stability tested simultaneously in the test rack. The tubes were placed in the rack twenty-four hours prior to the start of the test since MIL Spec. E-1/1110 (USAF) requires that the tubes be kept in darkness for this length of time before testing starts. When the tubes were put in the rack, they were operated and the filter was adjusted so that the anode current of each tube had the desired value at the start of the test. About one-half hour before the test was started, the lamp was turned on to allow it to stabilize. Unfortunately, some of the tests do not accurately represent the stability characteristics because often only two days were allowed for the tube to recover from a test before another test was started. It was not realized until late in the program that in some cases two days' time was insufficient for recovery.

2. Stability Characteristics Reproducible:

A series of five tests were performed on five 7029's to determine whether or not stability characteristics are reproducible. These tubes were not current production tubes. Since 7029's were both expensive and in short supply, it was decided that testing techniques would be developed and some of the tests would be made using a group of tubes which were available in the laboratory. Furthermore, there was the possibility of tube damage during the early stages of technique development. The only difference between the tubes measured and the then current product was that they had not been given a special temperature treatment for stabilization. There was considerable evidence that the special

stabilization treatment changes the magnitude but not the nature of the fatigue. The percentages of fatigue from the tests of these tubes were calculated and the results are tabulated in Table #6.

Table No. 6

Test No.	No. of Days After Previous Test	Time of Test (Min.)	Tube No.	Per Cent Fatigue*				
				8.8.2217	11.8.87	11.8.48	10.8.20	10.8.41
1	0	330		-16*	+2, -8	-29	-13	+27
2	4	330		-16	-10	-31	-15	+31
3	3	330		-17	+6, -9	-29	-14	+16
4	5	290		-17	-16	-29	-16	+11
5	2	290		-16	-15	-27	-17	+11
6	3	300		-16	-13	-27	-6	+24
7	7	310		-15	+5, -5	-28	-11	+28
8	4	320		-12	+2 -7	-30	-13	+10
9	5	320		-22	-19	-34	-26	+18
10	3	315		-23	-23	-36	-32	+3
11	14	330		-19	-23	-38	-	-16

* + Indicates positive fatigue
 - Indicates negative fatigue

At the termination of the first test of these tubes, all equipment was turned off, but the compartment in which the tubes were mounted, was not opened. The second test was then performed four days later under identical conditions. The results of these tests indicated that stability characteristics were reproducible. The question then arose as to what results would be obtained if the tubes were exposed to light between tests and if the light spot were moved on the cathode. (The light spot used was approximately one-eighth inch in diameter.) Therefore, a third test was run three days after the second under identical test conditions except that the position of the light spot on the cathode was changed. With the exception of one tube (#10.8.41), the changes in the stability characteristics of these tests were small.

The initial high rate of fatigue in these tubes indicated clearly that the time of making the initial current reading after opening the light shutter must be controlled accurately. Therefore, after two days the tubes were gain tested under the same conditions (fourth test). The position of the light spot on the cathodes was then shifted and after two days the tubes were again tested. The results of the fourth and fifth test are shown graphically in Figs. 43, 44, and 45. From these curves, one can conclude that stability characteristics are reproducible. Although the characteristics of Tube #10.8.41 are questionable, a later test shows that instead of increasing the anode current decreased. This indicates that the tube was not sufficiently processed and one would not expect stability under these conditions.

3. High Temperature Storage Tests:

The effects of high temperature storage were examined with the same tubes that were discussed above. However prior to this, an investigation was begun to determine what effect various aging processes would have on these tubes. The first stage of this endeavor was to expose the cathode to a high light intensity with a total of 90 volts applied between the cathode and third dynode for a period of three hours. All dynodes beyond the third and the anode were at the same potential as dynode #3. Following this treatment, the tubes were again tested. From the tabulated data, Table #6, it is observed that the fatigue in three of the tubes showed no appreciable change while the other tubes showed severe changes. At this point the remainder of this program was cancelled because we had been requested to investigate the effect of high temperature storage.

Following Test #6, the tubes were kept at a temperature of 70 to 78 degrees C for fifty hours, then tested (#7) and again heated to 70 to 78 degrees C for fifty hours. Test #8 was then performed after two days. After four days, during which time the tubes were kept at normal room temperature, Test #9 was performed. The data from Test #'s 6, 7, 8 and 9 were plotted and is shown in Figs. 46, 47, 48, 49 and 50. From these curves and the tabulated data, it is evident that high temperature storage had a very severe effect on these tubes but that some of the change was time delayed.

After two days, the tubes were tested a tenth time. The percentage fatigue, with the exception of Tube #10.8.41, changed only slightly (see Table #6). The tubes were then operated continuously for four days and, after approximately one week, they were tested the last time. It may be noted from Table #6, that the behavior of #10.8.41 finally became normal, i.e., the anode current decreased with time. This is what might have been expected from an insufficiently processed tube. In this case, the tests and high temperature storage apparently have proved to be substantially equivalent to normal processing and aging.

Figs. 51 to 55 show the test results of five additional tubes that were tested before and after high temperature storage. The percentages of fatigue from these tests are as follows:

	Time of Test (Min.)	Tube No.:	Per Cent Fatigue 8.8.2209	6.8.2038	11.8.31	6.8.2120	11.8.45
Before Storage	255		-15	-20	-25	-22	-11
After Storage	275		-21	-31	-51	-44	+18

The second test was made about one week after the high temperature storage. With the exception of tube #11.8.45 for the second test, the initial anode currents were between 8 and 10 ua. Tube #11.8.45 apparently decreased in sensitivity due to the high temperature storage. For the second test, the initial anode current of this tube was 1.7 ua. With the exception of tube #8.8.2209 (Fig. 51), all the tubes showed a considerable change in anode current in the second test.

Two production tubes which were rejected for lack of stability were kept at a temperature of 72 to 74 degrees centigrade for fifty hours. The tubes were tested twice before the high temperature storage and once after storage. The second test was made three days after the first and the third was made five days after the high temperature storage. The stability characteristics of these tubes are shown in Figs. 56 and 57. Tube #3.9.25, Fig. 56, was relatively stable while the fatigue in tube #12.8.25, Fig. 57, showed a sharp increase. The initial anode currents for these tests were between 8 and 10 ua. From these tests, it was concluded that high temperature could, and probably would, adversely affect the stability of the 7029. However, the fact that tube #3.9.25 survived the high temperature storage period with only a minor change in stability indicates that it might be possible to produce tubes whose stability is substantially independent of high temperature storage.

4. <u>Effect of Differential Baking and Aging:</u>

Some of the tubes that were used for high temperature storage tests were differential baked. That is, the tubes were placed in small

ovens with only those sections of the tubes on which the cathode is formed exposed. With this arrangement, the temperature adjacent to the bulb around the dynode cage structure was raised to 200°C while the temperature on top of the tubes was about 110°C. The tubes were kept at this temperature for one-half hour. After this bake the tubes were aged for eight days at high light intensity so that the anode current was about 1 ma. The circuit for aging this tube had high resistances in series with the dynodes so that the voltages to the lower number dynodes where the currents were small were considerably higher than for the higher number dynodes. Actually the voltages on the last few dynodes were such that the gains were unity. This arrangement was used so that all dynode currents are much higher than during normal operation. The processing just described is similar to the processing that is used for stabilizing the production 7029's. After the stabilizing process, two stability tests were made on three of the tubes. These three were then again stored at high temperature for 50 hours, and again tested. After the data were plotted it was seen that the stability characteristics were not reproduced before the high temperature storage. Therefore it was not possible to determine what effect the storage or the stability processing had on these tubes. A rheostat in the stability test rack was then found to be defective. It was believed that this caused the poor test results. However, as will be discussed later, stability characteristics may not be reproducible after a tube has been processed for stability unless considerably longer time is taken between tests. Five of the

tubes were stability tested about two weeks after the aging period of the stabilizing process ended. The percentages of fatigue are listed below:

Tube #	8.8.2209	6.8.2038	11.8.31	6.8.2120	11.8.45
% Fatigue	-12	-37	+7 -4	-30	+2 -9

It is seen that with the exception of #6.8.2038, the tubes improved. The initial dynode currents were somewhat lower for this test. This might be responsible for some of the improvement but it is doubtful that it would account for all of it. The data from this test, plus the data from tests to be discussed next, were plotted and are shown in Figs. 58, 59, 60, 61, and 62. The points of the curve that represent this test are indicated by an "X".

5. Stability Tests at Low Voltage and Current:

About five days after the test discussed above, these five tubes were tested again. Then after three more days, the tubes were tested at low currents. Next, after three more days, the tubes were tested at 825 volts instead of the standard 1000 volts. The data from these tests were plotted and are shown in Figs. 58 through 62. With the exception of tube #11.8.31, Fig. 60, these curves show what one would expect, i.e., the percentage fatigue is less at lower currents and voltages. Fig. 60 indicated that fatigue is not simply caused by cesium migration. If this were true, the positive fatigue of this tube (#11.8.31) should be as great at low currents as it is at high currents. The interesting fact about this tube is that the positive

fatigue was greater, or at least as great, at 825 volts as it was at 1000. There is considerable scatter of the points of this curve and it may be that the correct curve has not been deduced from the data. However, there is no doubt that the positive fatigue at 825 volts was at least as high as at 1000 volts. The stability characteristics of the first two tests of this series of four are not reproduced as well as was expected. At the time that these data were plotted it was thought that the defective rheostat mentioned previously might have been the reason for this. However, the effects of the rheostat was such as to cause sharp departure from the smooth curves and this would be noticed for every tube. This is not the case for the data just presented and it is now believed that the curves are reasonably accurate. As was mentioned previously, and as will be shown in the next section, to obtain reproducible characteristics the tubes should not be operated for any considerable length of time for at least several weeks before the stability test.

6. Recovery of Tubes from Fatigue:

It was suspected that the tubes might not recover from a five hour test in two days as had been initially assumed. Tests were then made on three tubes to determine the actual recovery time. Again, the tubes that were used for this test were identical to the production 7029's. except that they were not processed for stability. The procedure for these tests was as follows: The anode sensitivities of the tubes were first measured. (Prior to this, the tubes had not been operated for several months). After this test, the tubes were put in the stability test rack and operated for a short period of time to adjust

the filters to obtain the desired anode currents. The next day, the tubes were tested for $5\frac{1}{2}$ hours and immediately after the test was ended, the tubes were removed and the anode sensitivities were again measured. Five days later, the sensitivities were again measured. These test data are given below:

	First Test	Second (Stability)		Third	Fourth
Tube #	Anode Sensitivity	% Fatigue	Initial Current	Anode Sensitivity	Anode Sensitivity
6.9.2	22 ma/lumen	+9% -52%	8.8 ma	14	20
6.9.38	12	+15 -49	8.6	9.7	14
6.9.60	26	+15 -50	8.6	18	29

These data show that two of the tubes regained their sensitivy and actually increased somewhat within five days. The other tube nearly regained its initial sensitivity. It is possible that there are slight discrepancies in the data for the following reason. The light spot on the cathode was positioned to obtain the maximum current reading for the sensitivity test. It is possible that the fatigue from the five and one-half hours of operation could cause the position of the spot that yields maximum sensitivity to change.

Next, to further investigate the recovery of 7029's a series of four stability tests were made using five tubes of the standard factory product. The first test was made about seven weeks after the aging of the stabilizing process was completed. The second test was made two days later, the third was made two days after the second, and

finally the fourth test was made three days after the third test. The conditions for all the tests were the same, i.e., the light intensity and the supply voltage, which was 1000 volts as usual, were the same. Also the light spot was at the same position on the cathode each time; the tubes were not moved between tests. The tests lasted five hours. The percentage fatigue and the initial dynode current of each tube are given below for all the tests:

	Tube #									
	4.9.58		4.9.81		4.9.92		4.9.95		4.9.101	
Test #	% Fatigue	Initial Current	% Fatigue	Initial Current	% Fatigue	Initial Current	% Fatigue	Initial Current	% Fatigue	Initial Current
1	-27%	9.3 ua	-42%	9.4 ua	-32	8.5	-33	9.4	-30	9.5
2	+1, -9	7.6	+3, -20	7.1	+2, -16	6.7	+4, -13	7.0	+6, -16	8.1
3	+3, -7	7.4	+1, -18	7.2	+3, -13	6.4	+3, -10	6.7	+5, -8	7.9
4	+3, -8	7.6	+3, -22	7.7	+3, -14	6.5	+6, -10	6.7	+7, -10	8.1

It is seen from these data that two or three days is not sufficient time for the tubes to recover, and as a result the percentages fatigue of the tests are considerably less. The positive fatigue occurred within the first fifteen minutes. Later, another five hours stability test was made with these tubes. (Tube #4.9.81 broke due to glass strain and #6.8.2123 was substituted for it. This tube had not been processed for stability.) The tubes were not operated for five weeks prior to this test. After the test, recovery data was taken. That is, at the end of the test, the voltage was turned off and the tubes were kept in darkness, but later current readings were taken by turning on the voltage and exposing the tubes to light for a few seconds - just long enough to take a current reading. The voltage and light intensity,

of course, were the same as they were during the stability test. In this way, recovery data was obtained.

The data for these tests are plotted in Figs. 63 through 67. The unit of time is a two minute interval. This was done so that the fatigue and recovery could be shown in the same figure. No data were actually taken after two minutes of operation. The values for this point were obtained by making a linear approximation from the values obtained at zero and five minutes. The first recovery data were taken three days after the five hour test and therefore the shape of the curve for this interval is not known. However, a test on five other tubes, which will be discussed next, shows that the sensitivity of the tubes actually decreases after operation of the tubes is discontinued. Taking this into consideration, about the best curves that could be drawn with these data were the straight line shown. Tube #6.8.2123, Fig. 67, however, is an exception. Apparently this tube recovered rapidly and actually increased in sensitivity. This is in agreement with results obtained previously from tubes that were not processed for stability.

A series of tests were also made on another group of tubes to investigate the recovery of standard 7029's. This time, the first stability test was made four days after the stabilizing process ended. Then the tubes were not operated for three months. At the end of this time the second test was performed, and three weeks later the third test was performed. The percentage fatigue and initial dynode currents for these tests are given below:

Test #	4.9.70 % Fatigue	4.9.70 Initial Current	4.9.72 % Fatigue	4.9.72 Initial Current	4.9.73 % Fatigue	4.9.73 Initial Current	4.9.74 % Fatigue	4.9.74 Initial Current	4.9.90 % Fatigue	4.9.90 Initial Current
1	+4%	10 ma	+5, -7	8.9	+5, -9	9.5	+10, -1	8.3	+3, -7	9.1
2	-38	9.6	-37	9.3	-40	8.6	-27	8.8	-27	9.0
3	-34	10.0	-28	9.9	-33	9.0	-26	9.8	-21	9.4

Also the data for the third test, and recovery data for this test are shown in Fig. 68 through 72. The recovery data shown in the figures, however, is only for six hours. A reading was also taken three days later. These currents are as follows:

Tube #	4.9.70	4.9.72	4.9.73	4.9.74	4.9.90
Anode Current	7.6 MA	9.4	8.1	9.4	8.6

Note that the tubes continue to fatigue even though operation of the tubes has ended.

7. Operation of 7029's at High Temperature:

During the course of the program it was requested that we investigate the stability characteristics of the 7029 at 120°F. To do this, small ovens were designed which could be used to heat the tubes while they were being tested in the stability test rack. The design of the oven was as follows: A tube socket, identical to the socket in the test rack, was mounted inside and about 1/2" from the end of a hollow metal cylinder about 6" long and 2½" in diameter. Electrical connections were made between this socket and a standard 7029 base which was mounted in the end of the cylinder. Heating tapes were wrapped around the cylinder, and these in turn were covered with heat insulating ribbons. There was a hole 1/8" in diameter in the cylinder wall to admit light. A tube was put in the oven, the top of the oven was closed with

insulating material, and the whole unit was "plugged-in" the test ra k socket. The temperature inside the oven was measured with a thermocouple. The first oven that was constructed had three thermocouples so that a temperature gradient could be detected if it existed. The reason for the socket inside the oven was to avoid a temperature gradient inside the tube that could be caused by heat conduction through the tube base pins. Ten tubes were tested at 120°F. The first five were the ones that were discussed last in the preceding section - #4.9.70, 4.9.72, etc. The test was made about five weeks after any previous operation of the tubes. The ovens were heated about two hours before the test was started so that there was no doubt that the tubes would be in equilibrium. The data from this test are plotted in Fig. 73 thru 77. Note that after decreasing for several hours the currents seem to increase for a short period of time. It is doubtful that this actually happened. Apparently there was an error in monitoring the light or the voltage. At least this did not occur for the other five tubes that were tested. These five were also discussed previously; they were used to obtain data at low currents and low voltage. Prior to this test, the tubes had not been operated for two months. Again the ovens were heated about two hours before the test started. These data are plotted in Fig. 78 through 82. These data can be compared with those at room temperature - Figs. 58 to 62. Fig. 73 thru 77 can be compared with Figs. 68 to 72.

8. Special Stability Test of a 7029:

To obtain more information about the fatigue process a special test of a 7029 was made. In this test dynode currents as well as the anode current were measured. To obtain the necessary precision, the dynode currents were measured with the potentiometric voltmeter. The light source that was used is shown in Fig. 8. The regular laboratory test set, which is designed to test all types of multiplier phototubes, was used for this test. With this equipment, any dynode can be operated at ground potential. Therefore, the external leakage currents to that electrode will be at a minimum. Since an appreciable amount of time is required to make the current measurements with the potentiometric voltmeter, approximately ten minutes was required to obtain the initial set of dynode currents. Due to this spread in time between the readings, it was impractical to compute the stage gains. For these reasons and to simplify the presentation of the data the curves were plotted individually, the current at the ten minute point read from the curves, and the values at this time used to normalize the curves. The data in this form is presented in Fig. 83.

With this form of presentation, if all the dynodes showed equal fatigue, the curves would not be superposed. This is becúase the decline of current at any one dynode is produced by all the preceding dynodes as well as by the dynode whose current is measured. In fact, if the fatigue were equal in all the dynodes, the curves should fall in the same order as the number of the dynode

and the amplitude of the decline in the curves of the successive dynodes should be proportional to the terms of a geometric series. Furthermore, if the fatigue were simply and directly related to current density the amplitude of the decline in the curves of successive dynodes should increase even more rapidly. However there are counteracting influences, the area of the even numbered dynodes is greater than that of the odd numbered ones. Hence, the current density on the even numbered dynodes is lower; consequently, the fatigue of the even numbered dynodes might be expected to be less than that predicted by the geometric series, however, there is no obvious reason why its absolute value should be less than that measured for the preceding dynode.

9. Stability Characteristics of Tubes Made Using a Special Exhaust Schedule: In an attempt to improve the stability of the 7029, seven tubes were made that were differential baked while they were still on the pumps. The normal exhaust procedure was followed except for the cathode activation bake. For this bake the small oven, which was previously discussed, was placed over the tube leaving the cathode and window area of the tube exposed. Then the regular oven that is used with the exhaust system was raised to a temperature of 140°C and lowered over the tube. The temperature of the small oven, which was measured with a thermocouple was also raised and after 10 to 15 minutes it reached a temperature of about 200°C. These temperatures were then maintained for one-half hour. That is, the cathode was baked at about 140°C while the dynode structure was

baked at about 200°C. The initial tests results are given below. The tubes are listed in the order that they were made.

Tube #	Cathode Sensitivity	Anode Sensitivity at 1000 volts	Anode dark Current at 1000 volts
4.9.98	110 ua/lumen	12 A/lumen	0.01 ua
4.9.106	120	11	0.10
6.9.20	140	1.4	0.01
6.9.30	120	9	10
6.9.7	140	1.8	22
6.9.10	160	2.5	.045
6.9.16	140	14	.01
~~7029 limit~~	100 min.	10 min.	.05 max.

This experiment was very promising at first. The first two tubes met sensitivity and stability requirements. However, the other tubes, with the exception of the last one had low anode sensitivity and two had extremely high leakage currents. Tube #4.9.98 was aged for 5 hours after the sensitivity tests and then after three weeks it was stability tested for 5 hours. It fatigued 9% negatively during the five hours. The initial anode current was 8.5 ua. Tube #4.9.106 was stability tested two days after it was exhausted. The initial current was 4.8 ua but increased during the entire test and at the end of the five hours it was 5.9 ua. This tube was then aged for five days and, four days after the aging ended, it was stability tested. This time it fatigued 12% negatively during five hours. Tube #6.9.16 was aged while it was still on the pumps as well as being differential baked. After the differential bake, the tube was cooled and then covered with a black cloth through which only a small amount of light penetrated. The tube was then connected to a bleeder and a 1000 volt power

supply. An anode current of about 35 ua was drawn for six hours. Three days later, this tube was given the regular stability test. Its percentage fatigue was 1% positive and 10% negative. Six weeks after any previous operation these tubes were again tested and then three months later they were tested for the final time. The percentage fatigue for these tests is given below:

#4.9.98	#4.9.106	#6.9.16
-20%	-17	-16
-25	-18	+1, -23

With this high percentage of fatigue, the tubes would not pass the standard 7029 stability test. The stability data of the last test of these three tubes is shown graphically in Figs. 84 to 86. It is seen that the curves are similar to the regular 7029. Tubes #6.9.20 and 6.9.10, which had low anode sensitivities, were also tested. However, the initial currents of the tests were low. During the first test, the initial current for #6.9.20 was 2.7 ua and for 6.9.10 it was 0.9 ua. Tube # 6.9.20 fatigued 9% positively, 6.9.10 fatigued 36% positively. Tube #6.9.20 was then aged for one day. One month later, those two were again tested. Tube #6.9.20 read 4.9 ua during the entire test, while #6.9.10 again increased from 2.4 to 2.8 ua or 17%. Finally after three months they were tested the last time. Tube #6.9.20 fatigue negatively 4% while 6.9.10 again increased from 4.2 to 4.6 ua or 10%. Apparently this tube would have fatigued negatively after sufficient time or if it had been aged.

F. Stability of Modified 7029's

1. Introduction:

During the early part of the program, four tubes were made with AgMg dynodes and four were made with CuBe dynodes. With the exception of the dynode material and the weight of the charge in the cesium generator, the physical structure of the tubes was identical to that of the standard 7029. However, because of the different dynode materials, the tubes had to be processed differently. These tubes were not all processed at the same time. The ones with the AgMg dynodes were processed first but for discussion purposes, the ones with CuBe dynodes will be considered first. In general, the stability characteristics, of the tubes with AgMg dynodes apparently are better than those of the standard 7029. The characteristics of the ones with AgMg dynodes indicated that such tubes could be made very stable. Thus more of these were made later in the program. Also tubes were made that had Cs_3Sb secondary emitter surfaces formed on MgO substrates. These tubes initially had very high leakage currents and it was believed that no actual tests could be made. However, the leakage was reduced by differential baking, and stability tests were made on two of the tubes. These were very stable but time and available funds did not permit any further investigation.

2. Stability of 7029's with CuBe Dynodes:

a. General

Four of these tubes were made. Each tube had two 30 mg

cesium generators of cesium chromate and silicon in a 1 to 1 ratio by weight. Only one of the generators, however, was "flashed" because it was found that this produced sufficient cesium. Although the tubes were not processed at the same time, they were assembled at one time and since it was not known how much cesium was required, two generators were put in all the tubes. However, when one of the tubes was processed, both generators were "flashed" by mistake. This tube had very high leakage, and it was impossible to obtain any useful test data from it even after it was given additional "bakes".

b. Processing

A tube was sealed to the exhaust system in the evening and baked one hour at 300°C. The temperature was then reduced to 240°C until the next morning. Each tube was baked at least seven hours at 240°C. The temperature was then raised to 360°C and held for one hour. At the end of this time oxygen was admitted to a pressure of 2 mm Hg for 15 minutes. The MnO-Sb surface for the cathode was then prepared the same as is done for standard 7029's. The cesium generator was then "flashed" and the tube was baked at 140°C for 70 minutes and then at 150°C for 70 minutes.

c. Testing and Aging

The anode sensitivies and leakage currents for these tubes are given below:

Tube #	Anode Sens. 1250 volts	Leakage 1250 volts
4.9.84	27 A/L	.62 ua
4.9.103	4.4	.42
4.9.68	14	.10

Note that the leakage is very high for all the tubes. Tubes #4.9.84 and 4.9.103 were aged four days at 1000 volts. Tube #4.9.68 was aged four days at 1325. The anode current was between 25 and 35 ua. Four days after aging ended, tubes #4.9.84 and 4.9.103 were stability tested for four hours at 1325 volts. During this time, the anode current of tube #4.9.84 increased from 8.0 ua to 19 ua and the current of #4.9.103 increased from 8.5 to 26 ua. These two tubes were then aged again at 1325 volts for six days. The anode current of tube #4.9.84 increased from 20 to 41 ua and for #4.9.103, it increased from 8 to 34 ua. Two weeks later the two tubes were again stability tested, this time for five hours, and after four more days another test was made. It was then discovered that dynode #6 had accidently been defocused, i.e., the voltage distribution was uneven between dynode #6 and #7. After three more days another test was made with all the dynodes at equal volts per stage.

The data of these three tests were plotted and are shown in Figs. 87 and 88. Apparently, defocusing a dynode has little effect on the stability characteristics. The three stability tests were made at 1200 volts. The initial anode currents are as follows:

Tube #	First Test	Second Test	Third Test
4.9.84	7.0 ua	7.3	9.9
4.9.103	1.5	1.5	1.1

For some unknown reason, the sensitivity of tube #4.9.103 decreased after the 6 day aging period. Tube #4.9.68 was aged for four days at 1325 volts. The anode current increased from 25 ua to 34 ua during this time. Four days after aging, it was stability tested for five hours at 1200 volts. During the first fifteen minutes, the current increased from 7.7 ua to 8.3, which is about 8%, and then decreased to 7.8 ua in three hours where it remained for the remainder of the test. These three tubes were then given the regular production differential bake, i.e., the cage structure was heated to 200°C for one-half hour while the cathode temperature was kept at about 100°C. After baking the tubes were again aged for about four days at 1325 volts. The currents for #4.9.84 and 4.9.103 were between 20 and 30 ua while those for 4.9.68 ranged between 3 and 10 ua. About one month later the tubes were again stability tested at 1200 volts for five hours. The per cent fatigue and initial dynode currents were:

Tube #	Fatigue	Anode Current
4.9.68	-6	8.2
4.9.84	+61	9.2
4.9.103	+100	7.1

3. <u>Stability of 7029's with AgMg Dynodes</u>:

a. General:

Four of these tubes were made early in the program and, since fairly good results were obtained from these, eight more were made at a later date. These were processed differently than the first four. Also, platinum-antimony alloy evaporator beads were used to form the cathode instead of the pure antimony beads that are normally used. However, the sensitivities of some of the latter groups were very low and only four were stability tested. With the exception of the first two tubes, the cesium generator used in all the tubes had the same cesium content - 30 mg of cesium chromate and silicon having equal parts by weight. The first two had slightly more cesium - the generators contained 50 mg charge having 2 parts silicon to 1 part cesium chromate by weight. For convenience of discussion, complete results of the first four tubes will be given, and then the results of the latter group.

b. Processing (1st Group):

With the exception of the activation bake, the first two tubes were processed the same as the tubes with CuBe dynodes in the preceding section. Tube #4.9.85 was baked at 140° C. for 2-3/4 hours at 140° C. This long baking time was necessary to reduce the leakage in the tube. During the first fifteen minutes of the bake, the tube had been closed-off from the pumps. The second tube, #4.9.86 was baked 1-1/2 hours. This tube was closed-off from the pumps for only about five minuts at the start of the bake. The other two tubes were out-gassed differently. They were baked at 300° C. for three hours and then at 360° C. for one hour.

3. **Stability of 7029's with AgMg Dynodes:**

a. **General:**

Four of these tubes were made early in the program and, since fairly good results were obtained from these, eight more were made at a later date. These were processed differently than the first four. Also, platinum-antimony alloy evaporator beads were used to form the cathode instead of the pure antimony beads that are normally used. However, the sensitivities of some of the latter groups were very low and only four were stability tested. With the exception of the first two tubes, the cesium generator used in all the tubes had the same cesium content - 30 mg of cesium chromate and silicon having equal parts by weight. The first two had slightly more cesium - the generators contained 50 mg charge having 2 parts silicon to 1 part cesium chromate by weight. For convenience of discussion, complete results of the first four tubes will be given, and then the results of the latter group.

b. Processing (1st Group):

With the exception of the activation bake, the first two tubes were processed the same as the tubes with CuBe dynodes in the preceding section. Tube #4.9.85 was baked at 140° C. for 2-3/4 hours at 140° C. This long baking time was necessary to reduce the leakage in the tube. During the first fifteen minutes of the bake, the tube had been closed-off from the pumps. The second tube, #4.9.86 was baked 1-1/2 hours. This tube was closed-off from the pumps for only about five minuts at the start of the bake. The other two tubes were out-gassed differently. They were baked at 300° C. for three hours and then at 360° C. for one hour.

The same procedure was then followed as previously. For the one tube, #4.9.91, the activation bake was 140° C. for 65 minutes; for the #4.9.82, it was 85 minutes at 140° C. These two tubes were pumped continuously.

c. Testing and Aging (Group #1):

The initial anode sensitivities and leakage currents at the anode were measured at 1250 volts and are given below. The leakage of #4.9.82 was very high and no accurate measurments could be made.

Tube #	Anode Sens.	Leakage
4.9.85	12 A/L	.04 ua
4.9.86	2.5	.05
4.9.91	31	.07
4.9.82	-	-

Tubes #4.9.85 and #4.9.86 were then aged at 1000 volts for about three days in the regular production equipment. About one week after aging, these two were operated at 1325 volts for four hours. During this time the anode current of tube #4.9.85 increased from 8.8 to 10.1 ua or 15%. Tube #4.9.86 increased from 8.0 to 9.1, or about 14%, during the first ten minutes and then decreased to 8.4 ua. After this, tubes #4.9.85, #4.9.86, and #4.9.91 were aged for six days at 1325 volts. The initial currents were 22 ua and they increased to about 40 ua and then decreased slightly. These three were then stability tested three times at 1200 volts. The first test was made two weeks after aging, the second four days after the first, and the third, three days after the second. These data are shown graphically in Figs. 89 to 91. These tubes were tested at the same time that the two tubes with CuBe dynodes were tested, as discussed in the preceding section. Dynode #6 was also defocused for tube #4.9.85 for the first two of the series of three tests. All the tubes, including #4.9.82 were then given the standard differential bake. After this, they were aged at 1325 volts

for four days. The anode currents ranged between 15 and 25 ua. A series of six tests were then made on these tubes. The percent fatigue and the initial anode currents are given below. Also the time between the test and previous operation is given. All tests were made at 1200 volts and the time for all tests was five hours.

		Tube #							
Test #	Time after Previous Operation	4.9.82		4.9.85		4.9.86		4.9.91	
1	11 days	+10%	7.0 ua	+16%	6.8 ua	+16%	6.3 ua	+4½	6.4 ua
2	34	+6	7.2	+14	7.0	+10	8.1	+4½	6.9
3	36	+3½	8.2	+21	7.8	+12	8.6	-1	7.8
4	9	+6½	7.9	+23	7.8	+9	9.2	+2½	8.3
5	39	+7½	8.1	+21	8.2	+9	9.2	+3½	8.3
6	68	+2½	8.3	+22	8.2	+6½	9.2	+1	8.3

The percentage of fatigue is not constant, but these data show that apparently AgMg dynodes are far more stable than Cs_3Sb dynodes. Note that the tubes with the small percentage of fatigue are the ones containing the lesser amounts of cesium.

d. Processing (Group #2):

The first tube #10.59.119, of this group was processed as follows. After the tube was pumped down, manganese was evaporated. The tube was then baked at 300° C. for 1/2 hour and then at 425° C. for 4½ hours. Next, the temperature was decreased to 360° C. and oxygen was admitted to a pressure of 2 mm Hg for 15 minutes. The tube was then pumped down and cooled. The reason for evaporating manganese first was to avoid flushing the tube with oxygen at room temperature. Normally, manganese is evaporated after the tube is out-gassed, and cooled and then oxygen is admitted and the cathode

area is "glowed" to oxidise the manganese. One would expect some oxygen to be absorbed in the tube components at room temperature. For the activation bake, the tube was differential baked as discussed in Sec. IIE9a. This bake was for 45 minutes. The cathode temperature was maintained at 140° C., while the cage was heated to about 240° C.

The next three tubes, 10.59.121, 10.59.101, and 10.59.103, were processed as follows. Again, manganese was evaporated as soon as the tube was pumped-down. It was then baked at 300° C. for 1/2 hour and 360° C. for 1 hour. Oxygen was admitted to a pressure of 2 mm Hg for 15 minutes at 360° C. The tubes were pumped down and the temperature was raised to 425° C. and held for 4 hours. This much of the processing was done in the evening. The tubes were kept at 300° C. until morning. The tubes were then cooled and antimony was evaporated. Again, the tubes were differential baked for activation. They were baked at 140° C. for about 15 minutes. Then the temperature of the cage was increased to 240° C. The total baking time was 45 minutes. Tube #10.59.163 was processed nearly the same manner as the previous three tubes. The only difference was that after evaporating manganese the tube was baked at 300° C. until the following day when the remainder of the processing was completed.

The other three tubes were processed as follows. They were pumped down and baked at 300° C. for one hour. Then they were baked at 400° C. for two hours. Next they were cooled and antimony was evaporated. They were then baked one hour at 360° C. Oxygen was admitted at this temperature to a pressure of 2 mm Hg and held for 15 minutes. The tubes were pumped down and baked for 2 hours at 400° C. After cooling, antimony was evaporated and the cesium generator was flashed. The tubes were then differential baked in the same manner as the previous ones.

e. Testing and Aging (Group #2):

With the exception of tube #10.59.163, all the tubes of this group were aged on exhaust, i.e., the tubes were operated while they were still being pumped. The sensitivity of tube #10.59.163 was very low and no tests were made on it. The tubes were aged on exhaust so that any gas that might be removed when the dynodes were bombarded would be pumped out. It was observed that, when voltage was applied, the pressure did increase slightly, indicating that gas was released by bombardment. All the tubes were operated at 1000 volts. The time of operation and the initial and final anode currents are given below.

Tube #	Time	Initial Current	Final Current
10.59.119	4 hrs.	50 ua	66 ua
10.59.121	5	90	100
10.59.101	4	93	78
10.59.103	3½	90	90
10.59.120	4	90	120
10.59.147	2	90	140
10.59.148	4	90	-

The tubes were tested at 1200 volts with 10^{-6} lumens. The anode current and the leakage current at the anode are given below. The cathode luminous sensitivity is also given.

	Anode Current	Leakage	Cathode Sens.
10.59.119	2.5 ua	- ua	50 ua/lumen
10.59.121	26	0.1	90
10.59.101	10	.01	35
10.59.103	9	.03	32
10.59.120	18	.006	54
10.59.147	0.4	-	42
10.59.418	1.5	.004	53

With the exception of #10.59.121, the cathodes sensitivieies were extremely low. Later, tests will be discussed that were made with the platinum antimony evaporators to determine how to process the tubes to obtain higher

cathode sensitivities. Tube #10.59.121 was stability tested twice, both times at 1200V for 5 hours. The first test was made about one week after the tube was aged on exhaust; the second was made five weeks after the first. The initial current for the first test was 8.1 ua and for the second it was 8.6 ua. During the first test, it fatigued +1 and -4 percent. During the second test the fatigue was +4½ and -4½ percent. Tubes #10.59.101, 10.59.103, and 10.59.120 were stability tested three times. Each test was at 1200 volts for five hours. Tube #10.59.101 was aged on exhaust seven days before the first test, #10.59.103 six days before the test, and #10.59.120 two days before the test. The second test was made two months after the first, and the third two months after the second. The percentage fatigue and the initial anode currents of the stability tests are given below.

	10.59.101		10.59.103		10.59.120	
1st test	+2½, -2½%	7.9 ua	+1½, -1½	7.9	+5%	8.4 ua
2nd	-9	8.6	-7½	8.0	-8	7.9
3rd	-9	8.0	.6	8.1	-9	8.0

4. Stability of 7029's with Cs_3Sb Secondary Emitter Surfaces on MgO Substrates:

a. General:

Four 7029's were made with AgMg dynodes which were coated with a thin layer of antimony. That is, when processed Cs_3Sb secondary emitter surfaces were formed on MgO substrates. The MgO surfaces were prepared the same as those in Sec. IIDlb. Antimony was evaporated on the parts as discussed in Sec. IID3 so that the light transmission decreased to 25%. The bulb of one of these cracked just prior to testing. Another was exposed to air during processing when an attached ion gauge broke. All four of the tubes had ion gauges attached. They were to be used to investigate low frequency noise which will be described in Sec. III. The other two tubes had high leakage

currents and it was thought that no data could be obtained from these. However, the gauges were later removed and the leakage was reduced by baking. Stability tests were then made.

b. Processing:

The tubes were pumped down and baked at 240° C. for two hours. After cooling, the cesium generators were flashed. Each tube had two generators which contained 30 mg of cesium chromate and silicon in equal parts by weight. The tubes were then baked at 160° C. for 30 minutes while the tubes were closed off from the system. Next they were baked at 170° C. for 20 minutes while they were being pumped. The tubes were again cooled, antimony was evaporated, and the cesium generators were again flashed. The tubes were then baked at 140° C. for 45 minutes.

c. Aging and Testing:

The tubes were aged on exhaust at 1000 volts. Tube #10.59.210 was aged one and one-half hours with initial and final current 20 and 25 ua, respectively. Tube #12.9.12 was aged one hour with initial and final currents 15 and 24 ua. The tubes were then tested but no reliable data were obtained because the tubes had high leakage. The attached ion gauges were then removed and the tubes were differential baked for 1/2 hour. The cages were baked at 200° C. After the bake, the tubes were tested at 1200 volts and the following results were obtained.

Tube #	10.59.210	12.9.12
Cathode Sensitivity	140 ua/lumen	150
Anode current with 10^{-6} lumens at 1200 volts	150 ua	18
Anode leakage current at 1200 volts	0.4 ua	0.02

Two days after the bake, the tubes were stability tested at 1200 volts and about two weeks after this test they were stability tested at 1000 volts. These data were plotted and are shown in Figs. 92 and 93. It is seen that

the anode current first decreased and then after some time it increased. Apparently, secondary electrons originate both in the Cs_3Sb and the MgO. For the first part of the test, the shape of the curve is determined mostly by the decrease that usually occurs for Cs_3Sb but then the changes in the MgO become dominant and the current increases. Increases in current have, of course, been seen with Cs_3Sb but this almost invariably occurs initially and not after any decrease. Three weeks after the second stability test, the sensitivities of the tubes were checked at 1000 and 1200 volts.

	10.59.210		12.9.12	
	1000V	1200V	1000V	1200V
Cathode Sensitivity	140		120	
Anode Current with 10^{-6} lumen	60	250	7	26
Anode Leakage Current	.007	.024	.002	.008

III. FATIGUE OF A MULTIPLIER CONTAINING NO CESIUM:

Since fatigue is often attributed to the migration of cesium, an uncesiated photomultiplier tube was tested for stability. The RCA C-7180A, which is made for solar blind applications, contains no cesium. This tube has AgMg dynodes and a nickel oxide cathode. Since it is insensitive in the visible, the regular stable light source could not be used. Instead the necessary ultraviolet radiation was provided by a mercury vapor lamp (Hanovia Type 35A7-10, Ser. #0363N). An initial test showed that this lamp was quite unstable. Consequently in the second test, the lamp output was monitored by a photodiode. To avoid fatigue effects in the diode, it was exposed to radiation only briefly to check the lamp level each time a reading of the multiplier output was recorded. The results of the test are shown in Fig. 94. This curve strongly resembles the curves obtained

using multipliers with Cs_3Sb dynodes. It shows that, at best, the cesium migration hypothesis for explaining fatigue can only be partially correct and that fatigue effects occur in the absence of cesium.

IV. LOW FREQUENCY NOISE IN THE 7029:

A. Introduction:

To be suitable for its application, the noise current in the frequency band 0.06 to 10 cps in the 7029 must be less than 330 uua (peak to peak). This limit is established at a specified anode sensitivity (10 A/L). During the course of this program, the noise in the production 7029 increased and a considerable percentage of the tubes were rejected for this reason. Thus, an investigation of the noise was started. To test the hypothesis that the noise was associated with gas pressure in the tube, several tubes were made with ion gauges attached. The gauges were used to measure the pressure and reduce it after the tube was taken off the exhaust system. No conclusion could be made from this experiment. The possibilities of the noise being caused by ion feedback, meta-stable atoms, or light feedback were investigated. No positive results were obtained. Finally the association of the noise with thermionic emission was investigated. Although the results were negative, the test did indicate that perhaps the noise was associated with the cesium content. This was found to be a fact. Some of the difficulty encountered in the investigation was a result of the test equipment. It was found that the power supply was unstable.

B. Investigation of Gas Pressure:

Two tubes were made with ion gauges attached. These were processed the same as the standard 7029. The pressure of the one tube (#4.9.79) after it was removed from the system was 7×10^{-7} mm Hg. The cathode sensitivity of this

tube was 100 ua/lumen and the anode current with 10^{-6} lumens of light flux at 1000 volts was 22 ua. The low frequency noise of this tube was then measured over three weeks. The readings obtained varied between 150 uua and 6000 uua. The limit for this tube was 330 uua. During this time the tube was dark aged, i.e., high voltage was applied but the tube was in complete darkness. This apparently did not affect the noise. Next, the tube was aged at 1000 volts for a day. The initial anode current was 5.6 ua. During the three days after the aging, the noise varied between 250 and 350 uua. The tube was then pumped with the gauge for three days. The initial pressure was 7×10^{-7}mm Mg and the final was 3×10^{-7}mm Hg. The final reading, however, may not have been correct. Since the gauge apparently absorbed cesium, it could have produced photoemission and increased the current in the gauge. After pumping ceased, the noise was 500 uua. The following day it was 350 ua. The tube was then again pumped for 72 hours. Noise readings were taken during the next five weeks and it varied between 200 and 1800 ua. Similar results were obtained from the other tube, but the noise was even higher.

C. <u>Investigation of Feedback</u>:

Four tubes were made to investigate the possibility that the noise is caused by ion feedback or by meta-stable atoms. These four tubes were standard 7029's in all respects except that they had a thin metal shield around the dynode cage structure which is normally open. After the tubes were exhausted but before they were differential baked, they were stability tested. The noise for all of these was 2500 uua or higher. The tubes were then differential baked. During the next three

weeks the tubes were tested four times and at no time did any tube have noise sufficiently low so that it would meet test specifications. It is possible that the shield retained some of the cesium that is normally baked out during exhaust.

D. Investigation of Luminescence:

If photomultiplier tubes are operated at extremely high currents, a glow can be observed in the anode region. Thus, it was thought possible that the minute current resulting from thermionic emission might also produce light that could feedback to the cathode and cause photoemission and thereby cause noise. To check this possibility a tube was tested for noise in the usual manner. A voltage was then periodically applied to a second tube which was positioned so that any light that might be generated in the anode region would strike the photocathode of the first tube and increase its noise. The results of the test were negative. Next, the tubes were tested with a shield over the cathode area and also with a shield across the whole tube. These shields were operated at both cathode and anode potential during the noise tests. If the noise was generated by luminescence in the glass bulb in the cathode region, one could expect the magnitude to change by using the exterior shielding. However, this did not appear to affect the magnitude of the noise.

E. Investigation of Noise at Low Temperature

A tube was tested for noise at low temperature. The tube was connected to the power supply by a long flexible cable. The tube was then sealed inside a plastic bag which contained desiccant. It was placed in darkness and a noise reading was obtained. Next, the tube

was placed in a Dewar Flask and the flask was filled with dry ice. Noise readings were then made while the tube was cooling and it was observed that the noise decreased. After several hours, the noise had decreased by an order of magnitude. However, after sixteen hours (tube was still at dry ice temperature) the noise had increased to its initial value. Thus it was concluded that the noise was not due to thermionic emission. Large changes had been observed in the amplitude of the noise in other tubes and the large change observed here was not immediately associated with any particular phenomenon. Later, however, it was realized that this could be associated with free cesium on the dynodes. During cooling, the bulb temperature decreased much more rapidly than that of the cage. Thus the excess cesium in the tube condensed on the bulb and the noise decreased. However, after the tube was in thermal equilibrium the cesium was again equally distributed which caused the noise to increase. To definitely establish this, the test would have to be repeated on other tubes.

F. Cesium Content:

Ion gauges have been successfully used to reduce noise in Image Intensifier Tubes. The procedure is the same as discussed above. After the tubes were removed from the exhaust system, the gauges were used to pump the tubes and this lowered the noise. The gauge was then sealed-off from the tube. However, it was observed that considerable gas is evolved when the gauge is sealed off. The amount is comparable to what the gauge can absorb. The noise, however, remained at its low value after the gauge was removed. This indicates that the gauge may absorb a particular element that causes the noise. This fact,

plus the observation that was made above when the tube was cooled led to the thought that excess cesium might cause noise. The fact that the noise was reduced in image intensifier tubes and not in the 7029's could result because there was less excess cesium in the image intensifier initially. These tubes are processed differently than the multipliers and less cesium is admitted. On the other hand, it is doubtful that much cesium could be absorbed by the gauge since it is operated at very high temperature. However, as mentioned before, some cesium is absorbed because photoemission apparently occurs in the gauges. For this reason, less cesium was used in processing tubes with AgMg dynodes and, as a result, the noise was lower. This will be discussed further in the section on the Development of the C-70038.

G. Effect of Power Supply

During the course of the program it was suspected that perhaps the power supply that was used to make the noise tests was unstable. Another supply was then used, but no difference was observed in the noise. However, later a test was made that showed that the power supply that was normally used did contribute to the noise. This was done by replacing the tube with a resistor and capacitor unit such that the impedance was roughly the same as that of the tube. Fluctuations were then observed on the scope. Another supply, which is well regulated, was subsequently used for these tests.

V. CONSTRUCTION OF THE 7029

A. Metal Flange Design:

Some 7029's have failed due to strain cracks in the vicinity of the seal. The seals are made rapidly and are not fully annealed because complete annealing results in over-heating the tube mount, thus damaging

the electrical characteristics. To eliminate this problem a new envelope was designed. In this envelope, both the stem and bulb are sealed to metal flanges. The final seal is then made by a heliarc weld between stem and bulb flanges. Hence all annealing can be done prior to mounting and overheating of the tube parts is eliminated.

Some difficulty was encountered in making the tubes with metal flanges. First, one of the dies that was made to form the flanges was defective which, of course, caused the flanges to be defective. This defect in the die was corrected and the flanges that were then made were satisfactory. Then, when tubes were made, strains were caused in the glass stems during the welding process. The stems cracked from this strain either during welding or later when the tube was being exhausted. To overcome this problem, a welding jig was made. The jig holds the tube firmly during welding and also removes heat by conduction. Four envelopes were then made to test the jig and to determine the speed and temperature at which the weld should be made. All of these envelopes were later exhausted and heated to 400° C. No cracking occurred which indicated that tubes could be made free of excess strain. As an additional test, two complete tubes were then made with flanges. Both of these were operable.

B. <u>Alignment of Tube Components</u>:

An investigation was made to determine the optimum distance between the cathode and first dynode for best collection efficiency. Improving the collection efficiency improves the signal to noise-in-signal ratio of the tube. This program was actually started before

the contract was awarded. It was found that if the distance was increased by one-eighth inch, the collection efficiency was improved. However, poor alignment of the tube components made it impossible to determine the exact spacing required. A mounting jig was then designed to improve the alignment of the tube. The jig holds the multiplier structure and stem assemblies in the proper position while the stem leads are welded to the multiplier structure. It was then planned to make about twenty tubes with variations in the cathode to shield spacings and variation in the multiplier structure behind the shield. However, after three of these were made, it was realized that the sealing process would also have to improve because poor alignment here negated the improved alignment of the multiplier structure and stem. But at this time work was being done on the tubes within metal flanges and the problem of poor alignment during the final seal (heliarc weld) did not exist. Thus, the fabrication of the tubes with variations in the location of the components was postponed. The mounting jig was then revised so that it could be used to make tubes with metal flanges. These tubes can now be made with very good alignment of the parts and a very uniform product can be obtained. Unfortunately, by the time that the metal flange design was perfected, time did not permit making any tubes with the variations mentioned above.

VI. PROCESSING PROBLEMS

A. False Transparency Readings during Antimony Evaporation:

At the start of this program difficulty was experienced with the exhaust procedure of the 7029. To obtain good stability, this tube is processed differently than most photomultiplier tubes. Briefly, the

procedure is to sensitize the dynode surfaces before the cathode is formed. The dynodes are antimony coated before they are mounted in the tube. After the tubes have been baked on exhaust to out-gas the parts, manganese is evaporated onto the cathode area and oxidized. Cesium is then admitted to the tube and the tube is baked at a temperature of 150° C. for 30 minutes. Then after baking out the excess cesium, antimony is evaporated from a small bead onto the cathode surface. The thickness of the antimony coating is measured by light transmission. Difficulty was encountered with this evaporation.

Frequently the value of light transmission rose after or even during operation of the antimony evaporator. This difficulty could have arisen from two causes: (1) Cesium could have been deposited near the antimony evaporator bead and have been re-evaporated when the bead was heated, thus fogging the tube window, or (2) the Sb may have partially reacted with the cesium during the dynode activation bake to form Cs_3Sb on the surface of the bead; this compound would decompose on heating the bead, and the cesium, possibly by a secondary re-evaporation from hot surfaces surrounding the bead, condensed on the window surface. This problem has been eliminated by heating the antimony bead during cesiation of the dynodes and by increasing the length of the initial bake.

B. Platinum - Antimony Alloy Evaporator Experiment:

As previously mentioned, some of the 7029's that were made with AgMg dynodes also had platinum-antimony alloy evaporator beads instead of the pure antimony bead for formation of the cathode. This type alloy evaporator bead makes it possible to outgas the tubes at higher

temperatures and also eliminates particles that are known to be generated by the pure antimony bead. However, all the tubes that were made had low cathode sensitivity. Eight tubes were then made with this type evaporator bead to determine how to process them to obtain better cathodes. These tubes did not have the multiplier structure.

The tubes were out-gassed at 400° C. for 1½ hours. They were then cooled and manganese was evaporated so that the light transmission decreased 10%. Oxygen was then admitted to a pressure of 2 mm Hg and the tubes were glowed with R.F. The tubes were then pumped down and antimony was evaporated. Next, the cesium generator was flashed and the tubes were baked at 140° C. for maximum sensitivity. The thickness of the antimony layer was varied in these tubes. The decrease in light transmission during the evaporation and the cathode sensitivities are given below.

Tube #	% Decrease Light Trans.	Sensitivity ua/lumen
12-9-18	20	115
12-9-25	20	100
12-9-8	25	120
12-9-23	25	140
12-9-24	30	160
12-9-5	30	150
10-59-183	35	140
10-59-189	35	160

Normally, in the 7029, antimony is evaporated so that the light transmission decreases 20%. This is also the thickness that was used in those tubes with AgMg dynodes. Yet, none of those tubes had a cathode sensitivity as high as 100 ua/lumen. However, since good cathodes have been made frequently using platinum-antimony alloy beads in similar multiplier structures, it should not be concluded that there is any basic difficulty in using this type of evaporator. Time did not permit pursuing this point further.

VII. DEVELOPMENT OF THE C-70038

It was required by the contract that ten 7029's with improved stability characteristics be made and delivered to WADD. Because of the good results obtained previously with tubes that had AgMg dynodes, these were made with the same type of dynodes. Platinum-antimony evaporator beads were used because of the high cathode sensitivities that were previously obtained with them. Also, to obtain good alignment of the tube parts and to eliminate bulb cracking from glass strain, the tubes were made with metal flanges. This tube type was designated the C-70038. Considerable difficulty was encountered in making these tubes because of low frequency noise. As previously mentioned it was thought that the low frequency noise could be reduced by reducing the cesium content in the tubes. However, when this was done the tubes were very unstable. Later, difficulty was also encountered in making tubes with satisfactory cathode sensitivities. No reason could be found for this drop in sensitivity.

One cesium generator was used for the first two tubes that were made. It contained a 15 mg charge having two parts silicon to one part cesium chromate by weight. One of these tubes had a cathode sensitivity of 80 ua/lumen and its anode current at 1200 volts with 10^{-6} lumens was only 2.7 ua. The other had a cathode sensitivity of 110 ua/lumen and an anode current of 3.0 ua. Apparently the amount of cesium that was used was insufficient. Five tubes were then made with twice as much cesium. Four of these had two generators; each had a 15 mg charge in the same ratio as before. The fifth had only one generator but it contained a 21 mg charge with equal parts of cesium chromate and silicon.

The tubes were pumped down and out-gassed at 250° C. for one-half hour and then at 410° C. for two hours. The temperature was then decreased to 360° C. and oxygen was admitted to a pressure of 2 mm Hg for 15 minutes. The tubes were then pumped down and cooled. The cathode surface was then prepared as previously discussed and the cesium generators were "flashed". The tubes were then baked at 140° C. until maximum cathode sensitivity was achieved. This required a period of one-half to one hour. (The tubes were not all processed at the same time.) This was followed by a differential bake at 250° C. for one-half hour on exhaust. The tubes were also aged on exhaust for four hours at 1000 volts. The initial currents were between 20 and 40 ua. The test results obtained from these tubes are given below. The cathode sensitivities, the anode currents at 1200 volts with 10^{-6} lumens, and the low frequency noise currents and the voltages at which these were measured are given.

Tube #	Cathode Sensitivity	Anode Current	Low Frequency Noise Current	Low Frequency Noise Voltage
1	160 ua/lumen	10 ua	250 uua	1300 volt
2	160	12	200	1300
3	135	40	325	1200
4	190	16	200	1200
5	145	16	100	1200

However, these tubes were very unstable. The reason that this number of tubes was made before changing the process is that the first tubes were not tested immediately for stability to be sure that they had completely recovered from the aging on exhaust. It was not expected that these tubes would be unstable, so more were made before the first ones were tested. The first two fatigued negatively about 50% during four hours at 1300 volts. The next two fatigued negatively about 30% at 1200 volts

in only two and one-half hours. The fifth one fatigued negatively about 19% in only two and one-half hours. This one was also tested at 1200 volts. Next, a tube was made that had one generator with a 21 mg charge having equal parts of cesium chromate and silicon and one generator with a 15 mg charge with a 2:1 ratio of silicon and cesium chromate. This tube was processed the same as the previous five. However, it had to be baked nearly four hours to obtain a maximum cathode sensitivity reading and to reduce the leakage. This tube had a cathode sensitivity of 160 ua/lumen. The anode current at 1200 volts with 10^{-6} lumens was 70 ua. However, the low frequency noise at 1200 volts was 1000 uua. During two and one-half hours of operation at 1200 volts, the tube fatigued positively about 33%. The tube was then differential baked again, but it cracked during this process. Apparently, the temperature of the tube was changed too rapidly. Because the last tube had high noise and the baking time required was very long, the next tubes were made with less cesium. Three tubes had one generator with a 21 mg charge having equal parts of silicon and cesium chromate. Two of these, #7 and #8, were baked 2½ hours during activation and the other (#9) was baked nearly five hours. It was not understood why these required such a long baking time when the tubes that were previously made "baked-out" faster. These three were again processed the same as the previous ones, except that #7 was not aged on exhaust. The test results of these were as follows:

Tube #	Cathode Sensitivity	Anode Current 1200 volts - 10^{-6} lumen	Low Freq. Noise 1200 volts
7	160 ua/lumen	2.6 ua	300 uua
8	185	3.0	125
9	40	8.0	800

The anode currents of #7 and #8 were low and the cathode sensitivity of #9 was very low. Tubes were then made that again had more cesium. A small amount of aquadag was painted on the interior of the metal flange. This was used as a getter to remove excess cesium. It was thought that this would absorb the excess cesium after the tube was processed and cooled, but apparently it became saturated at high temperatures. These tubes also had low sensitivity. At this point all the tubes that were made had low cathode sensitivities. Because it was believed that this might have been caused by contamination of the platimun-antimony evaporator beads, the regular pure antimony beads were then used. Although this improved the tubes somewhat, many of them still did not have cathode sensitivities that were high enough to meet specifications. These tubes that were made with the pure antimony bead were baked out at only 360° C. so that no antimony would evaporate during the bakeout. More tubes were made with different amounts of cesium and they were differential baked at different temperatures, both on exhaust and after processing. The best results were obtained from tubes which had one generator with a 21 mg charge of equal parts of silicon and cesium chromate and which were processed as follows. The tubes were outgassed at 360° C.; the activation bake was one hour at 140° C. The tubes were then differential baked after they were removed from the exhaust unit at 220° C. for one-half hour.

7: SUMMARY AND RECOMMENDATIONS

The results of the experiments and the tests that were performed provided information for the development of an improved version of the RCA-7029 photomultiplier tube. This new tube type, designated as the RCA-C70038, has AgMg dynodes which are more stable than the Cs_3Sb dynodes used in the 7029. It has an improved envelope design, which eliminates the severe glass strain that frequently causes the bulbs of the 7029 to break (sometimes months after fabrication) and which provides a more uniform product in regard to some of the electrical characteristics by better alignment of the tube components. It is a better tube with respect to the noise current in the frequency band 0.6 to 10 cps. This low frequency noise was minimized by improved control of the cesium content of the tube.

While 7029's with standard Cs_3Sb secondary emitter surfaces can be made stable temporarily by special processing, the stabilizing process apparently leaves the tubes in a non-equilibrium state and in a period of a few months when they reach equilibrium, most of the improvement in the stability characteristics is lost. Some tubes were "stored" at a temperature of 70 to 78°C for fifty hours after they were "stabilized". This treatment decreased the time required for the tubes to reach equilibrium, as one would expect. Unfortunately, it was not fully realized until late in the program that the improvement in stability was only temporary. Also, it was initially assumed that the recovery time from fatigue caused by a five hour test was less than two days. This is true for a tube that has not been processed to improve stability but for one that has, the recovery time is at least two weeks. For these reasons, much of the data reflects the properties of

tubes which have only partially recovered from the effects of previous operation or processing. Nevertheless, it was established that stability characteristics of the 7029 are reproducible and that they are not significantly different at 120°F than at normal room temperature. Also, it was proved that migration of cesium can only be partly responsible for fatigue.

The (Cs) MgO secondary emitting surface formed from silver magnesium alloy used in the C70038 is the most stable of the secondary emitting surfaces investigated. Unlike the 7029 with standard Cs_3Sb dynodes, the improvement in stability of the C70038 resulting from suitable differential baking is permanent. While the percentages of fatigue of two tests made under identical conditions but separated by a month or two may differ slightly, the change is not practically significant.

Multipliers having improved stability were also made with copper-beryllium alloy dynodes. Although, in general, the multipliers that were made with these dynodes ((Cs) BeO secondary emitting surfaces) were not as stable as those with AgMg, tests of the single-stage multiplier tubes that were made with one AgMg and one CuBe dynode indicated that the stability characteristics of these two materials are basically the same. Probably too much cesium was used in the 7029's with CuBe dynodes. Hence, while CuBe alloy may well be as satisfactory for stability as AgMg, until this point has been fully established by further testing, AgMg must be used in tubes requiring the best stability characteristic.

K_3Sb was investigated as a possible substitute for Cs_3Sb in the 7029. Although it was not expected that the secondary emission yield of this surface would be as high as that of Cs_3Sb, it was thought that it might be considerably more stable because it has a lower vapor pressure. The test results indicated that K_3Sb is more stable, but the yield is too low to be of any practical use in the 7029.

Although no new method was found to improve the stability of the standard Cs_3Sb secondary emitting surface by different and improved processing procedures, it was discovered that the stability of this surface can be improved by forming it on substrates other than nickel oxide. When very thin layers of Cs_3Sb formed on MgO and BeO substrates were compared with the standard Cs_3Sb dynodes in the single-stage tube, the former were considerably more stable. Two 7029's were also made that had Cs_3Sb surfaces formed on MgO. The stability data that were obtained from these indicated that this composite surface was potentially very promising. Time limitations, however, prevented pursuing this development to the point where it could be considered for use in production tubes. Cs_3Sb surfaces of standard thickness were also formed on MnO and gold substrates in the single-stage tube. The ones on MnO were more stable than the standard dynode, but the ones on gold were not. It is plausible that a tube with such composite secondary emitting surfaces can be made that will provide both stability and high gain. It is recommended that these surfaces be further investigated.

It was established that the low frequency noise (.06 to 10 cps) is associated with the cesium content of the tube. It was previously assumed that this

noise was associated with the total gas pressure of the tube but no such relation was discovered. Tests were also made to investigate the possibilities that the noise was associated with thermionic emission, but again no positive results were obtained. It is probable that noise at higher frequencies is also associated with cesium. Because reduction of noise would greatly enhance the usefulness of most multipliers it is recommended that this phenomenon be further investigated.

Early in the program an attempt was made to optimize the cathode-dynode shield spacing. However poor mount alignment prevented establishing the optimum spacing. The improved mount alignment resulting from the configuration used in the C70038 will permit the optimum spacing to be more precisely determined. Insufficient time was available subsequent to the development of the C70038 mount structure to permit completion of this work. This dimension should be optimized.

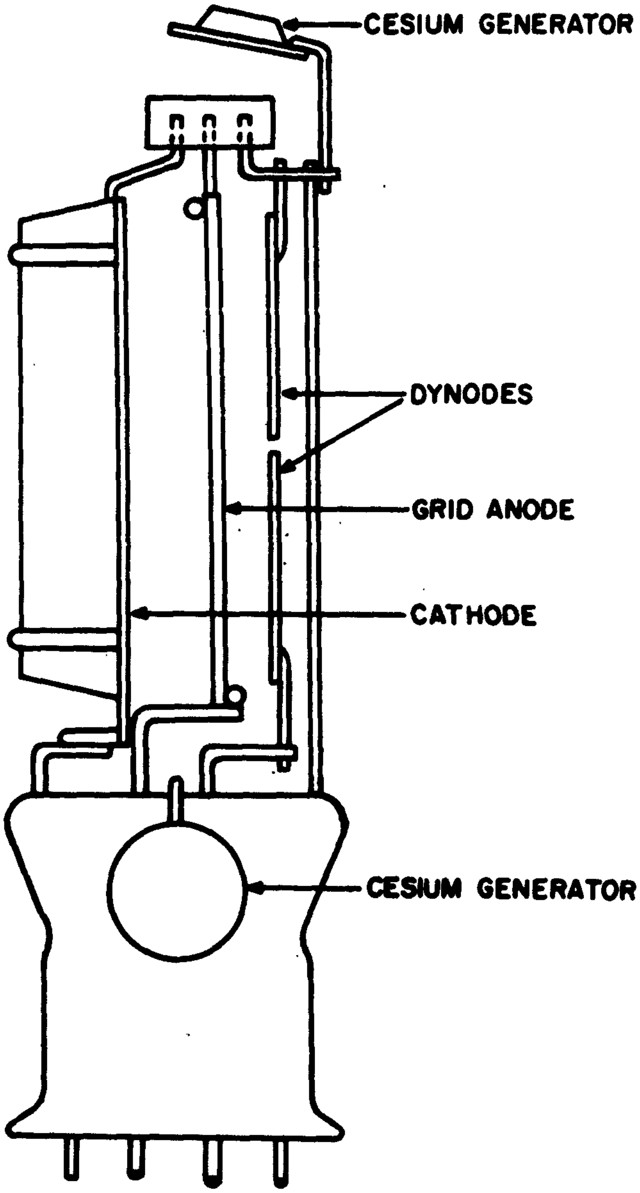


Fig. 1 - Single-stage Photomultiplier Tube Mount

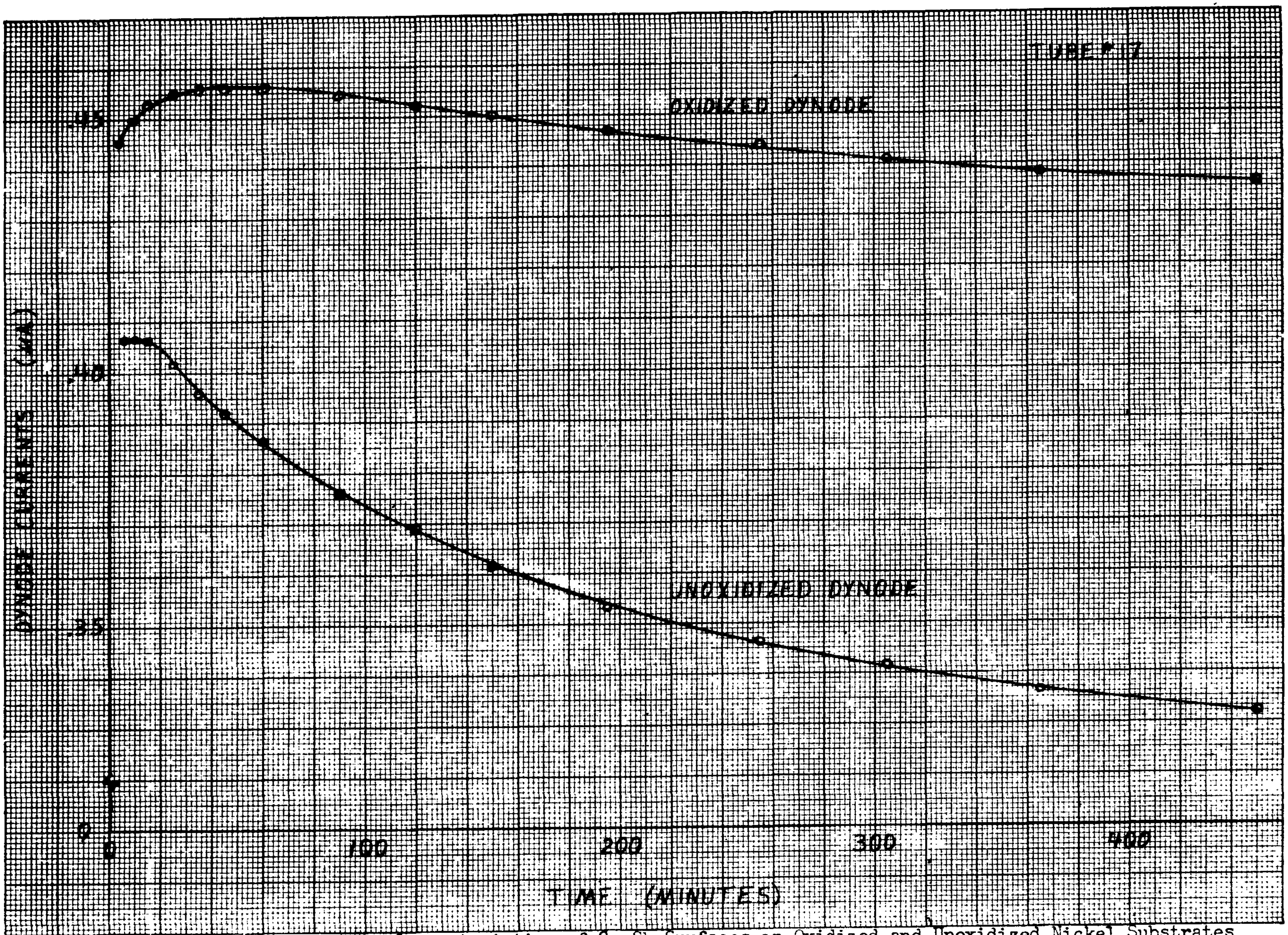


Fig. 2 - Stability Characteristics of Cs_3Sb Surfaces on Oxidized and Unoxidized Nickel Substrates in a Single-stage Tube (C-7290)

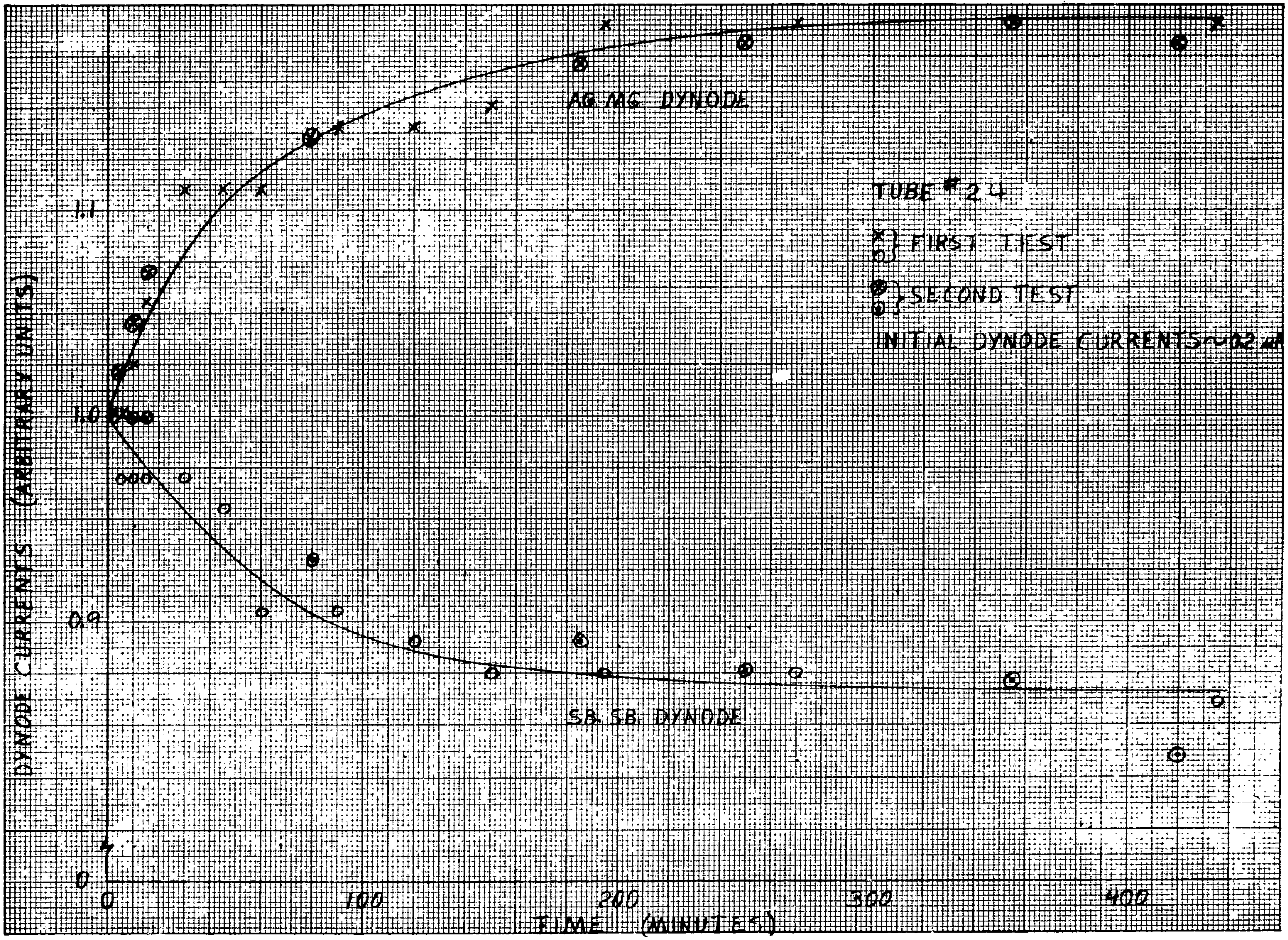
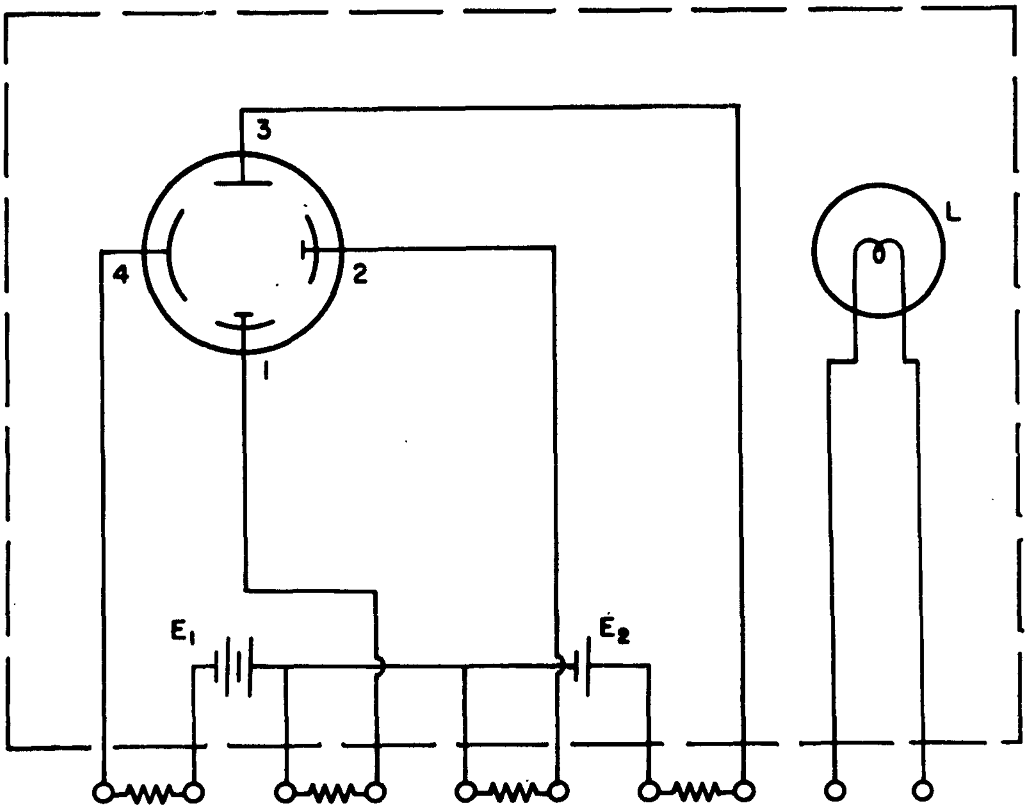
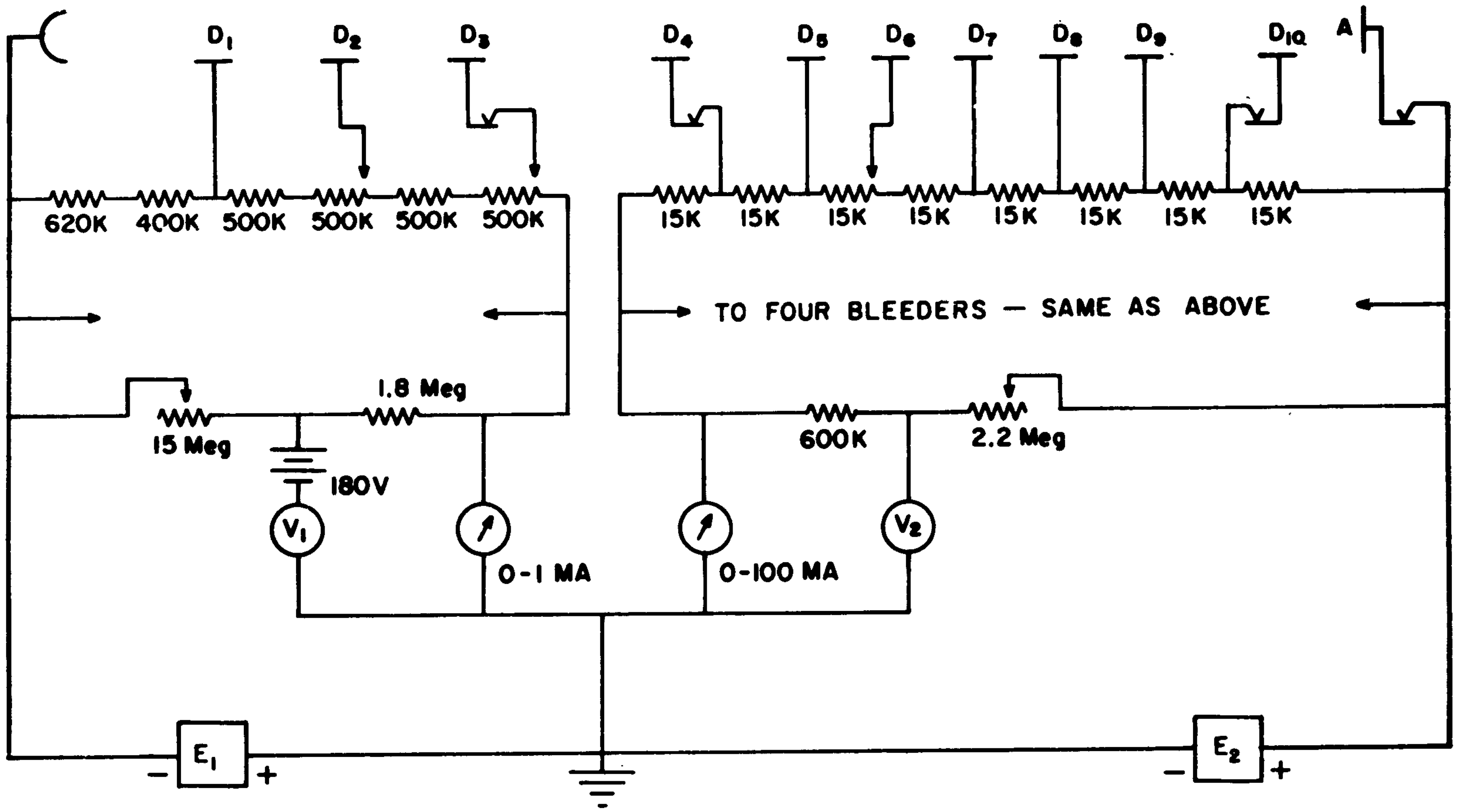


Fig. 3 - Stability Characteristics Showing that Fatigue is Reproducible in the Single-stage Tube (C-7290)



1 DYNODE
2 DYNODE
3 ANODE
4 CATHODE
L LAMP GE No. 48 (SEE FIGURE 6)
NOTE: VOLTAGE OF E_1 IS TWICE THAT OF E_2

Fig. 4 - Stability Test Set for Single-Stage Multiplier Phototube



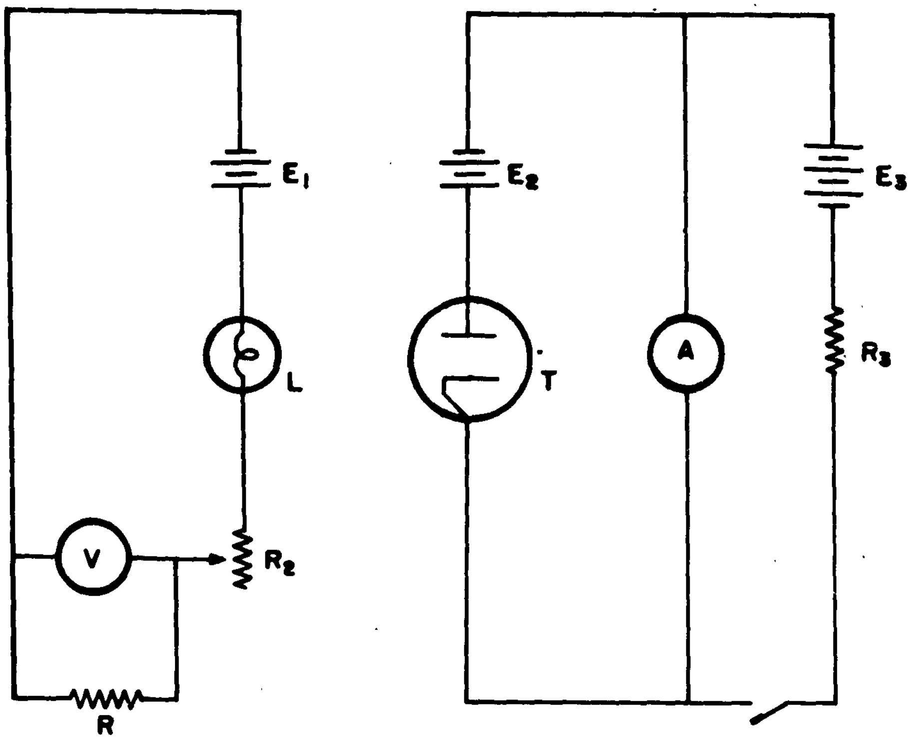
V_1 MODEL WV-98A SENIOR VOLTOHMYST, RCA

V_2 MODEL 801 POTENTIOMETRIC DC VOLTMETER, JOHN FLUKE MFG. CO., INC.

E_1 DC POWER SUPPLY LAB. MODEL

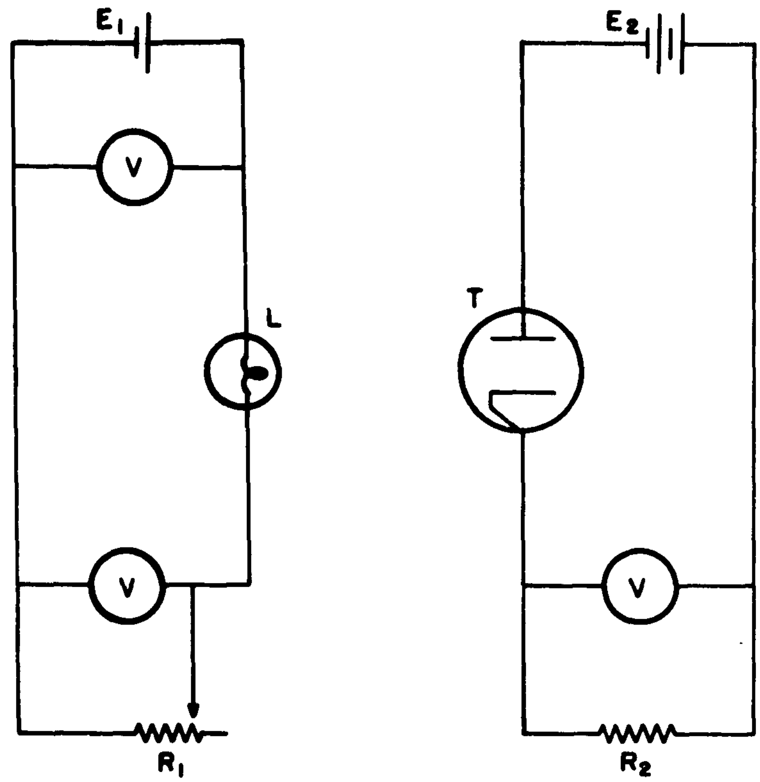
E_2 MODEL 2500 VOLTAGE REGULATED DC POWER SUPPLY, KEPCO LAB., INC.

Fig. 5 - Stability Test Rack for Multiplier Phototube



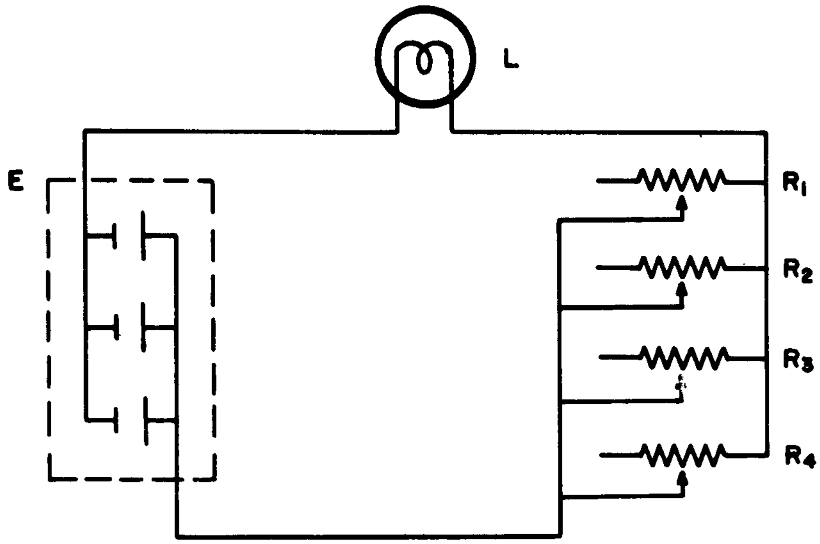
L	No. 48 GE LAMP
T	No. 935 RCA PHOTOTUBE
E_1	2 VOLTS
E_2	90 VOLTS
E_3	345 VOLTS
R_3	950 MEGOHMS
V	POTENTIOMETRIC VOLTMETER

Fig. 6 - Circuit for Measuring Lamp Stability



L	No. 48 GE LAMP
T	No. 935 RCA PHOTOTUBE
R_2	1.8 MEGOHMS
V	POTENTIOMETRIC VOLTMETER
E_1	2 VOLTS
E_2	2 VOLTS

Fig. 7 - Circuit for Measuring Lamp Stability



L No. 48 GE LAMP 2 VOLTS - .060 AMP.
E CONVENTIONAL STORAGE BATTERY WITH CELLS CONNECTED IN PARALLEL.
R_1 15,000 OHMS
R_2 1,000 OHMS
R_3 125 OHMS
R_4 27 OHMS

Fig. 8 - Light Source for Stability Test Sets

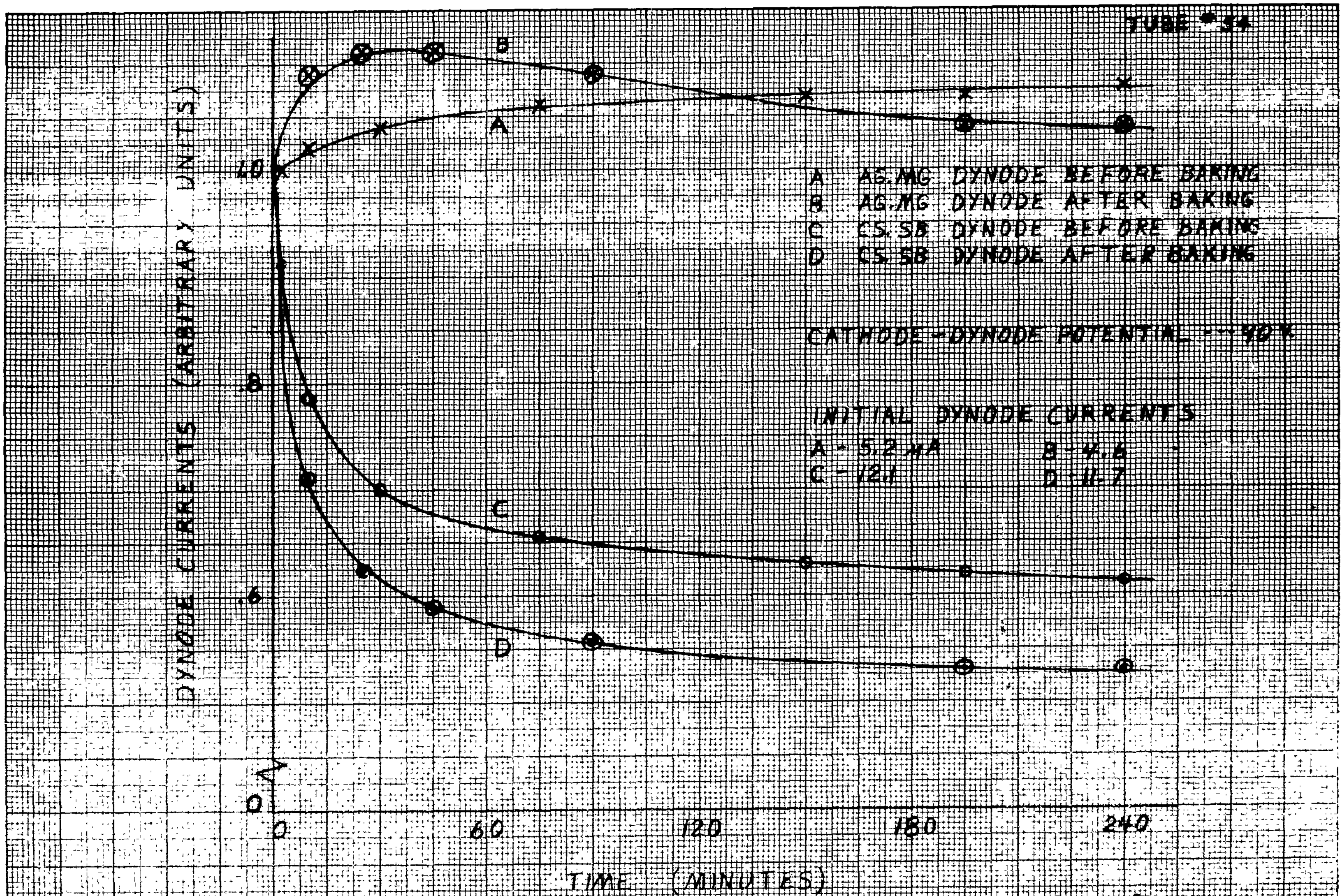


Fig. 9 - Comparison of Stability Characteristics of a AgMg and a CsSb Dynode in the Single-Stage Tube (C-7290) before and after Baking and Aging.

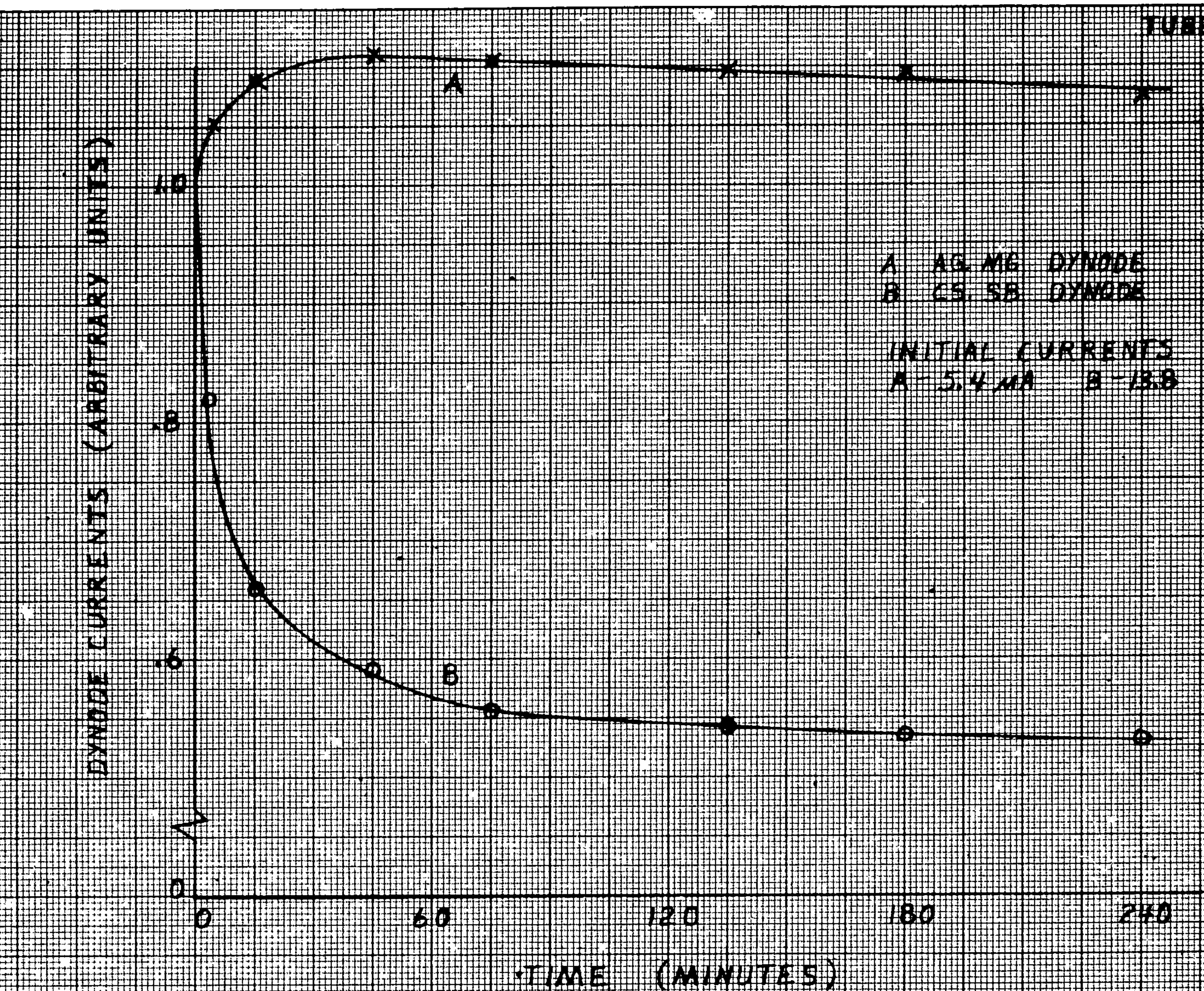


Fig. 10 – Comparison of Stability Characteristics of a AgMg and a Cs_3Sb Dynode in the Single-Stage Tube (C-7296) at 114 Volts Dynode Potential.

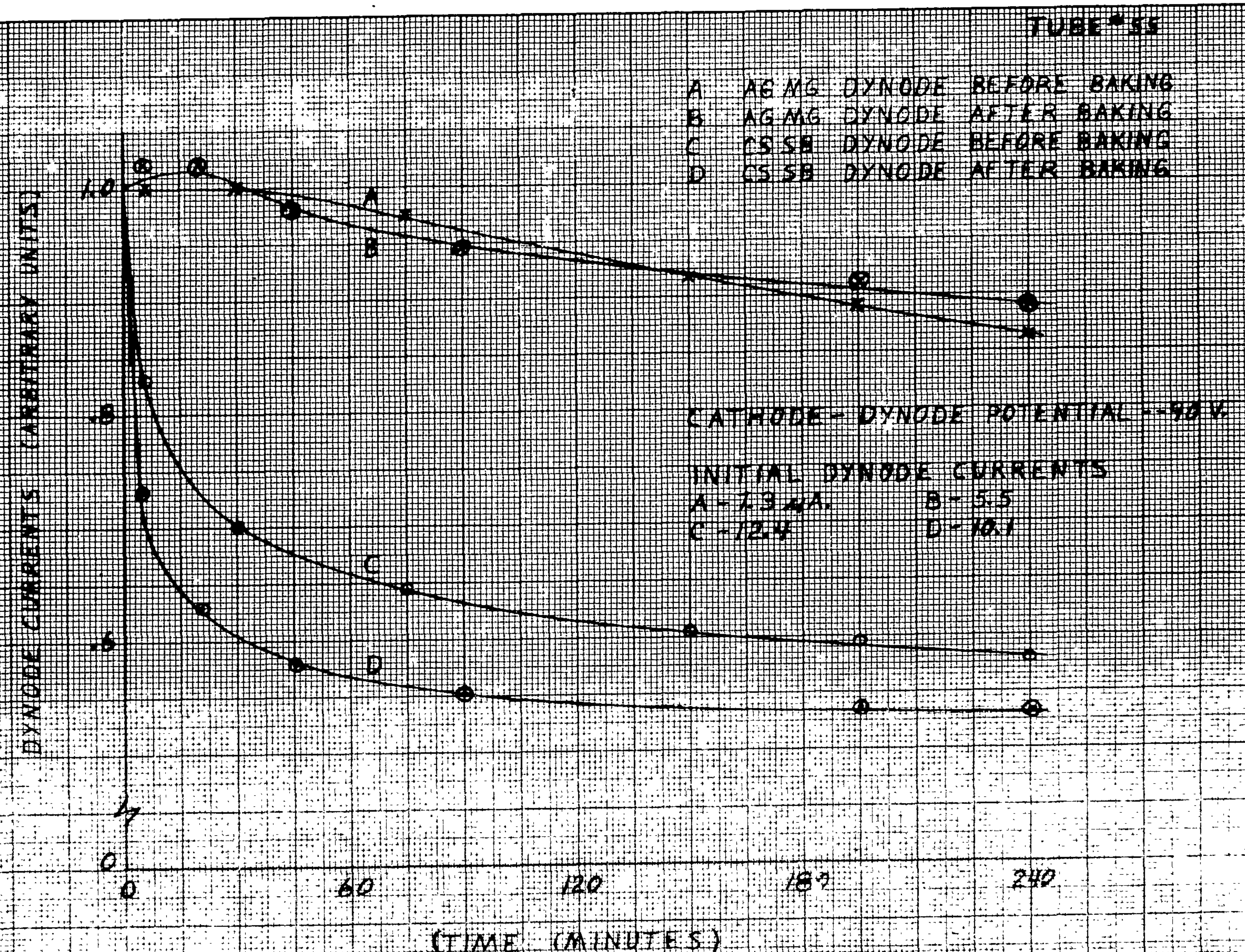


Fig. 11 - Comparison of Stability Characteristics of a AgMg and a CsSb Dynode in the Single-Stage Tube (C-7290) before and after Baking and Aging.

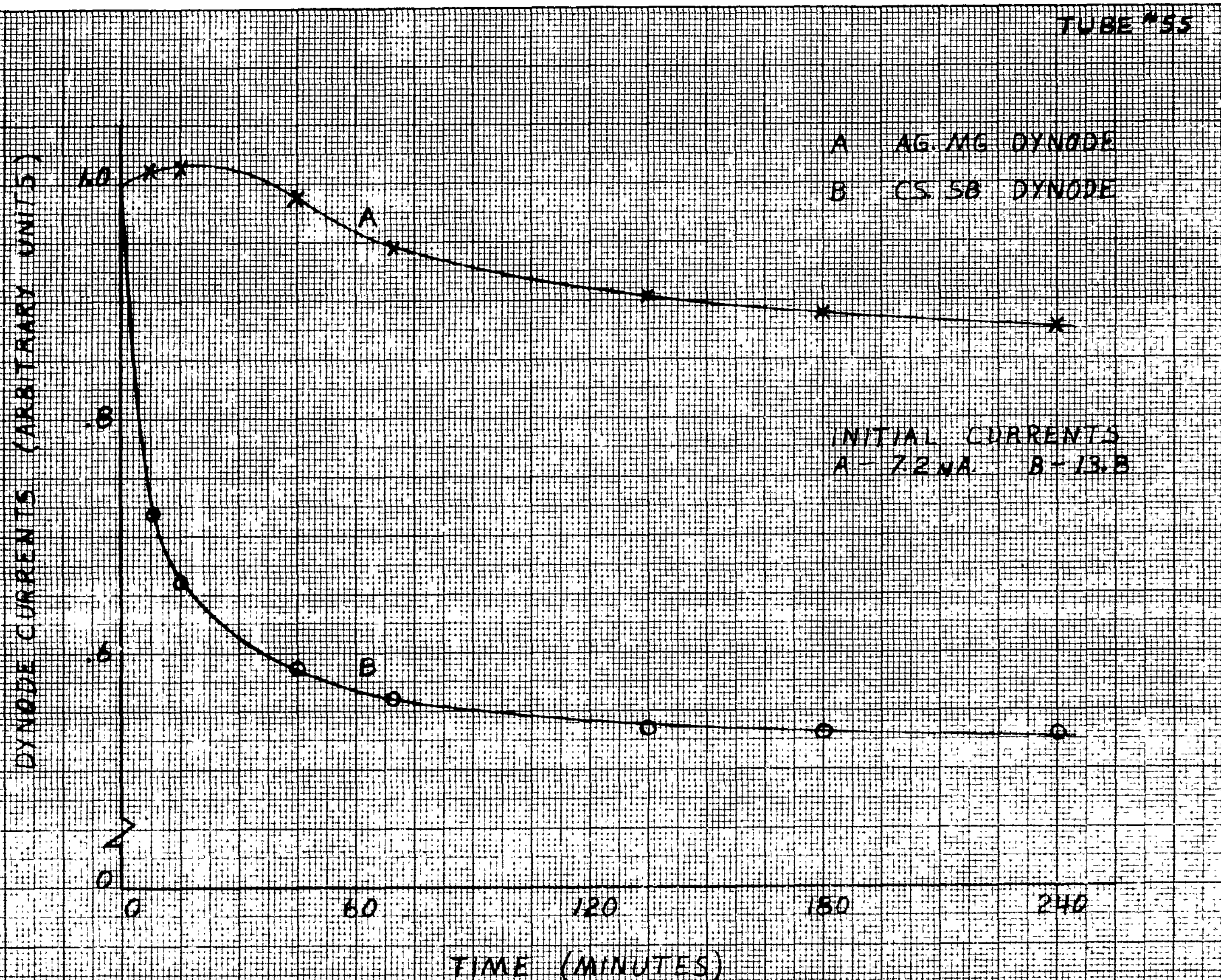


Fig. 12 - Comparison of Stability Characteristics of a AgMg and a CsSb Dynode in the Single-Stage Tube (C-7290) at 114 Volts dynode potential.

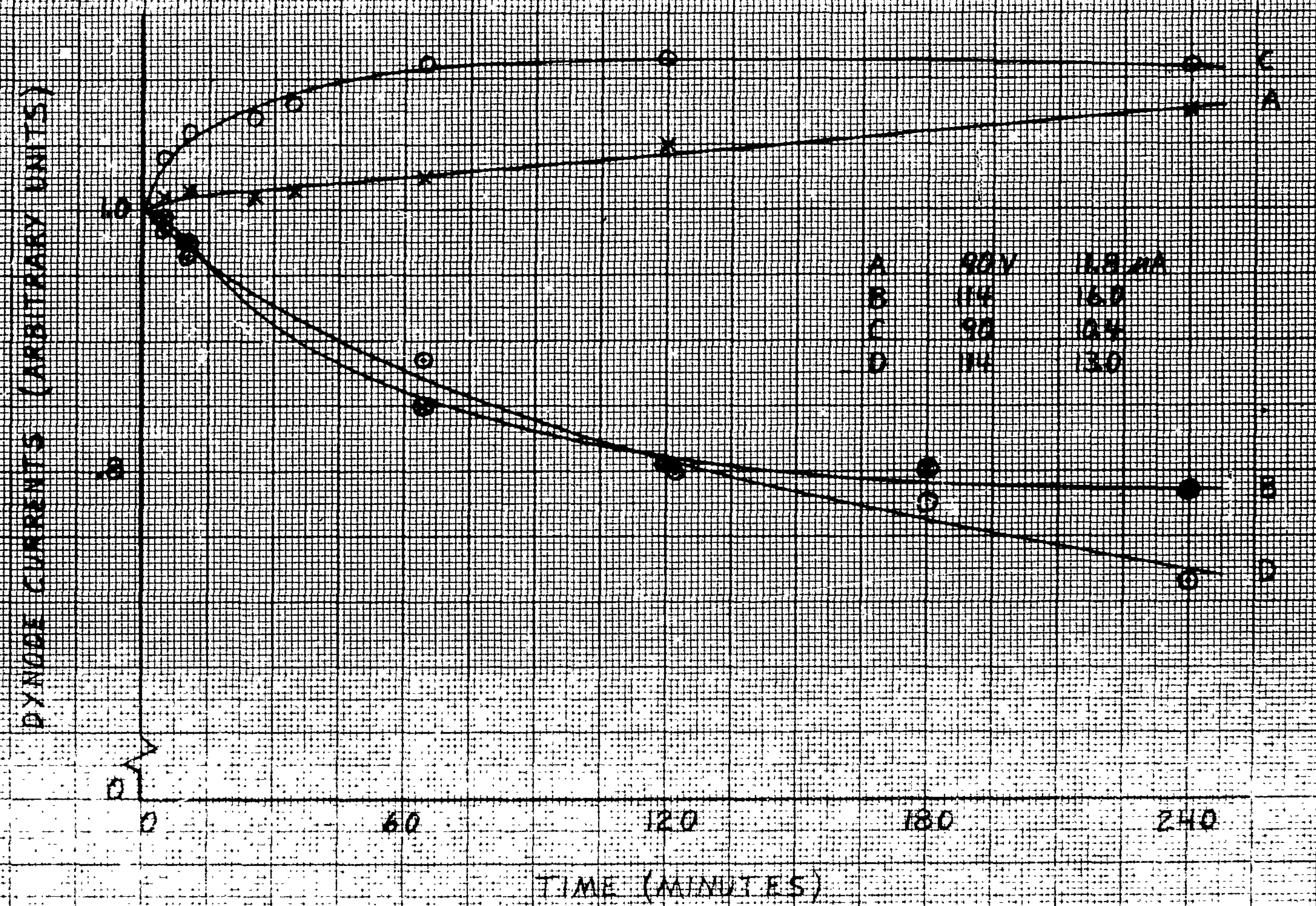


Fig. 13 - Stability Characteristics of AgMg Dynode at 90 and 115 Volts. Curves A and B are for the Bottom Dynode; Curves C and D are for the Top Dynode. The Currents that are Given are the Initial Dynode Currents.

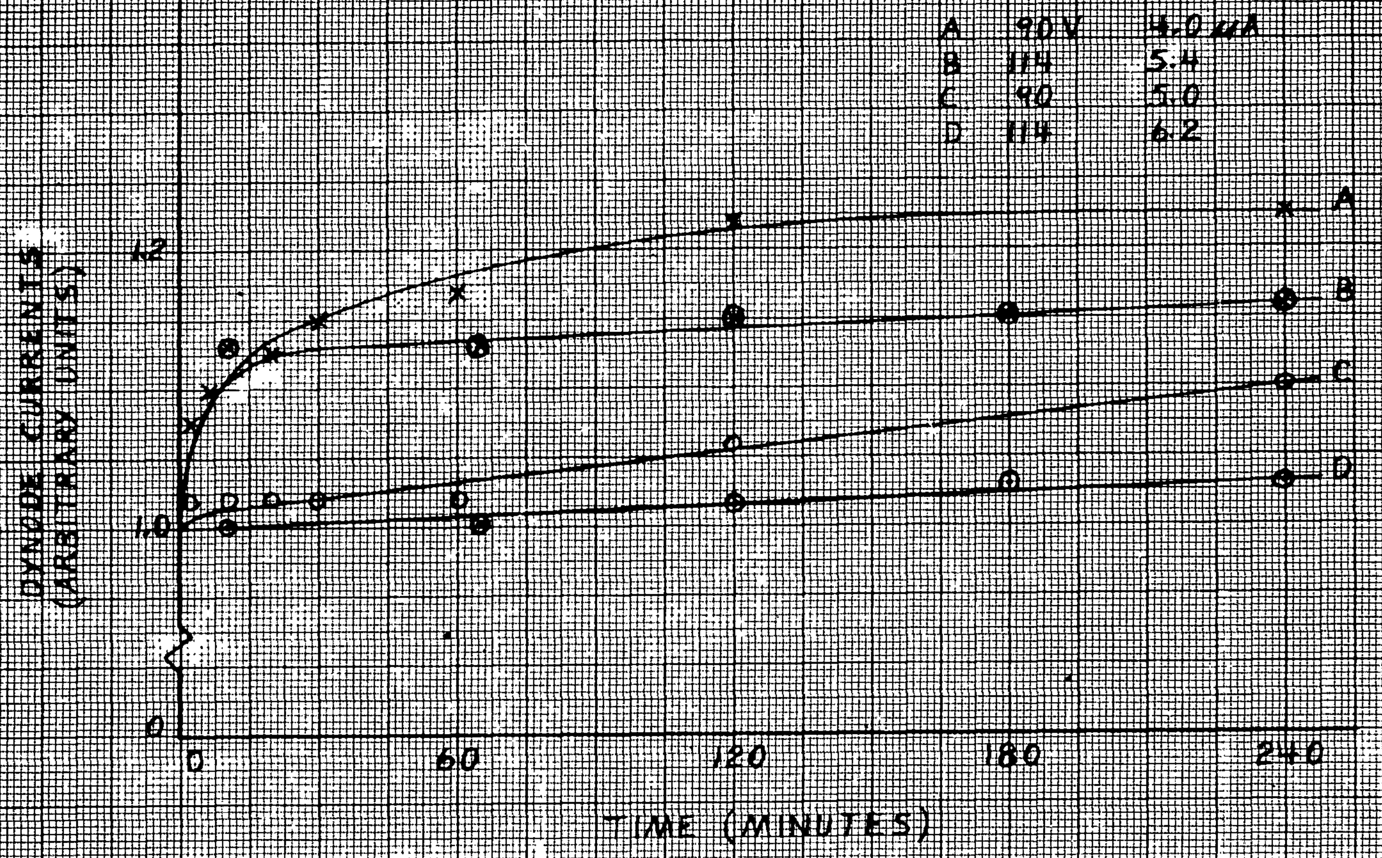


Fig. 14 - Stability Characteristics of AgMg Dynodes at 90 and 115 Volts. Curves A and B are for the Bottom Dynode; C and D are for the Top Dynode. The Currents that are Given are the Initial Cathode Currents.

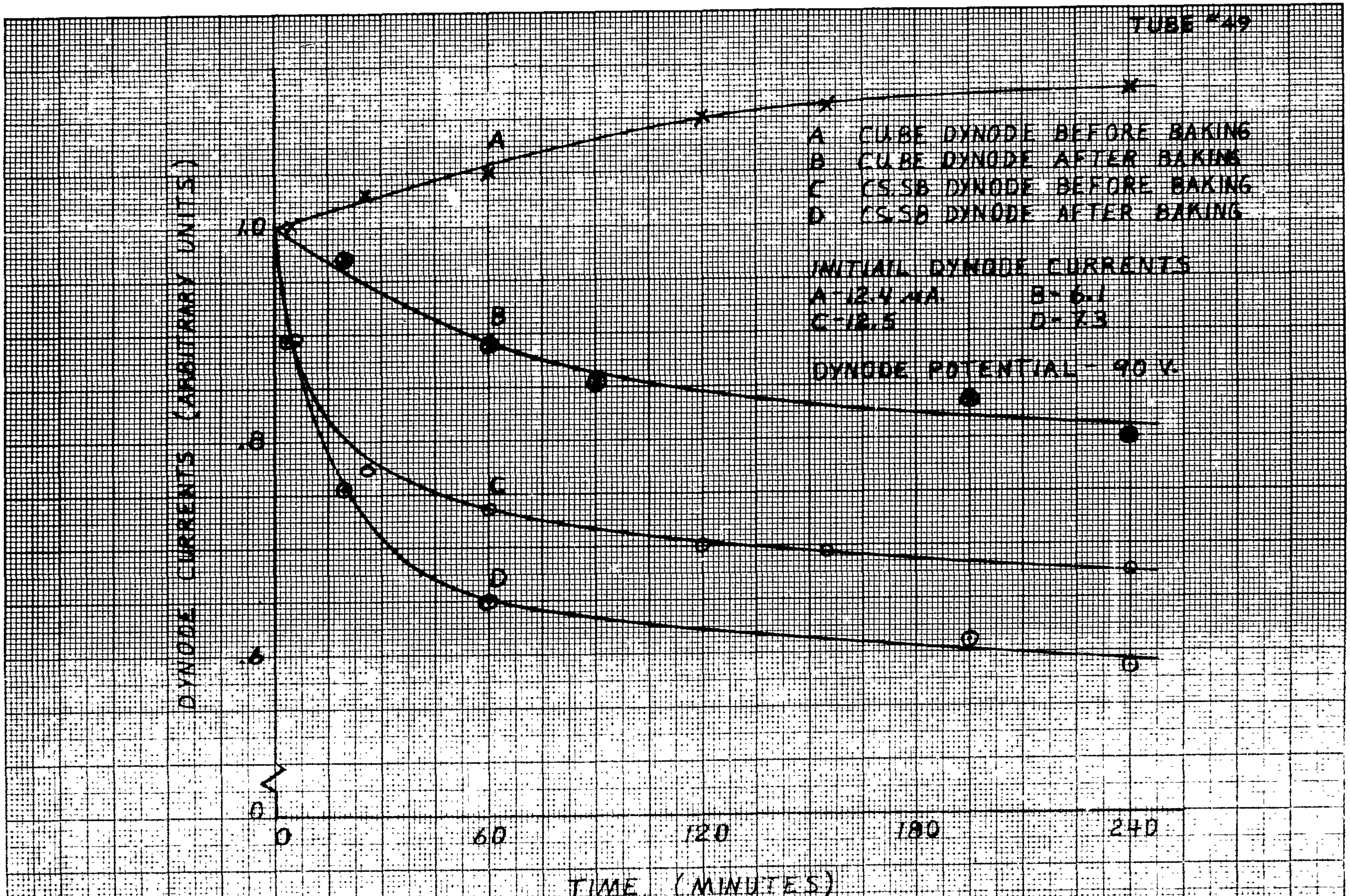


Fig. 15 - Comparison of Stability Characteristics of a CuBe and a CsSb Dynode in the Single-Stage Tube (C-7290) Before and After Baking and Aging.

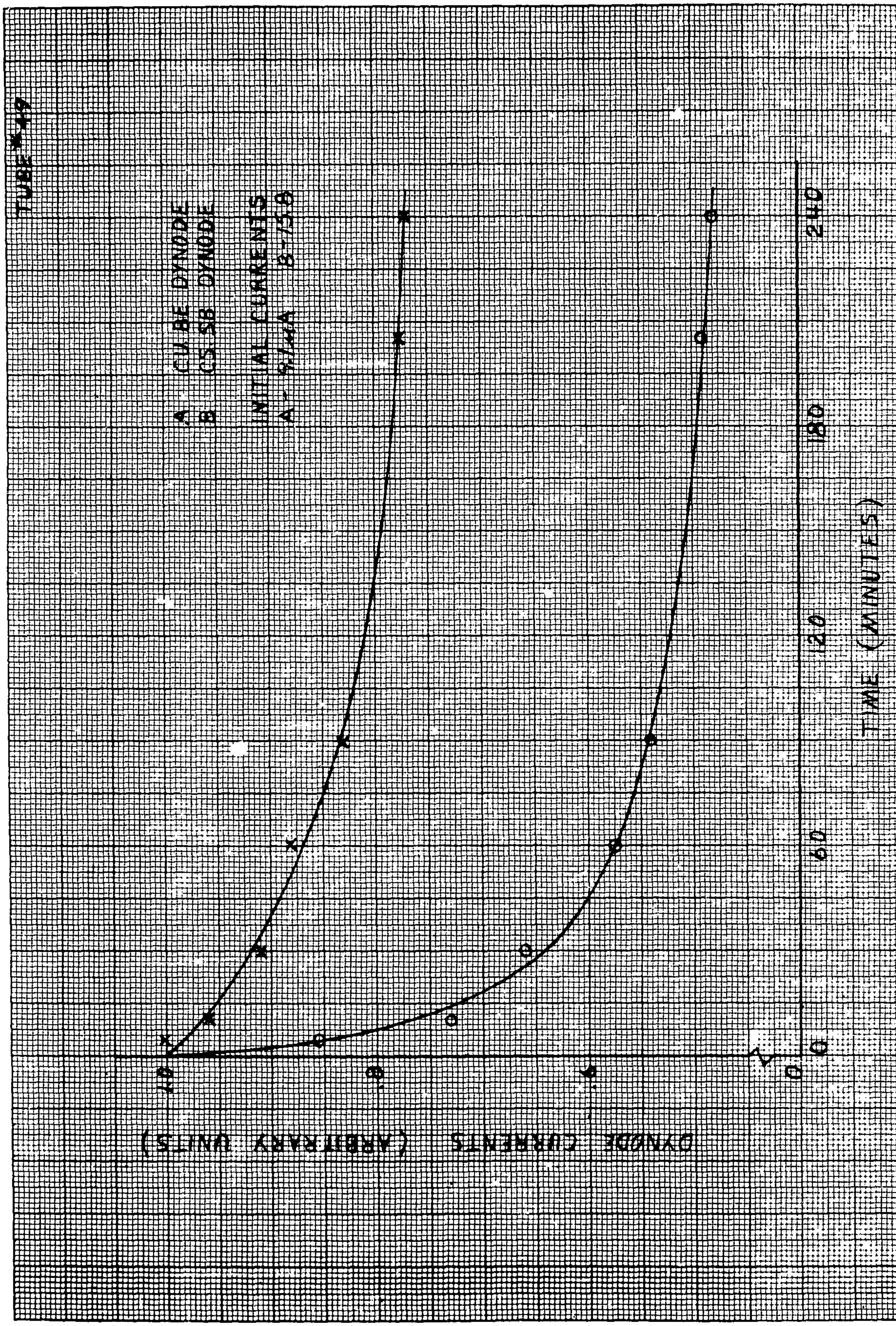


Fig. 15 - Comparison of Stability Characteristics of a CuBe and a CsSb Dynode in the Single-Stage Tube (C-7290) at 114 Volts Dynode Potential.

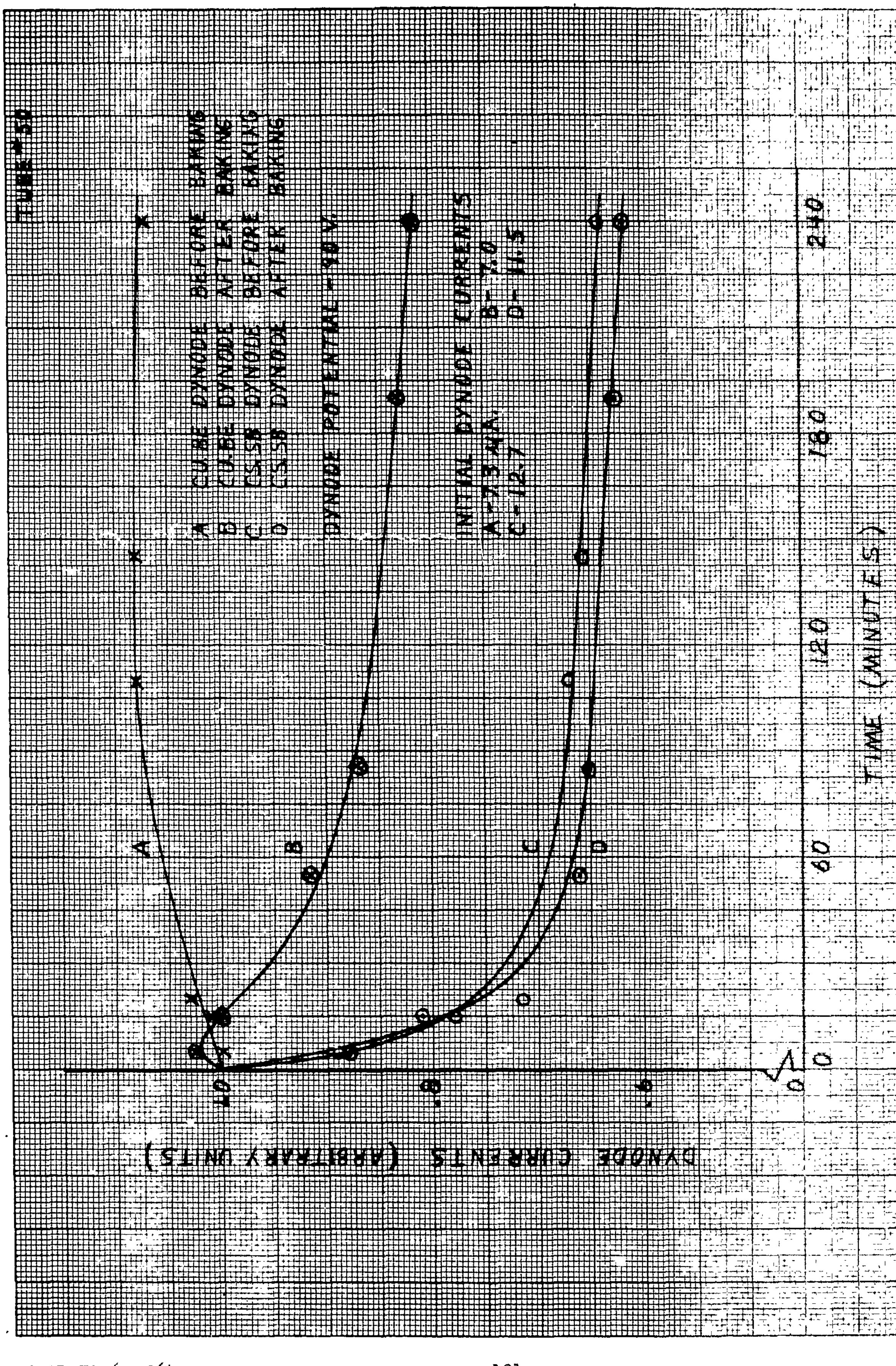


Fig. 17 - Comparison of Stability Characteristics of a CuBe and a CsSb Dynode in the Single-Stage Tube (C-7290) Before and After Baking and Aging.

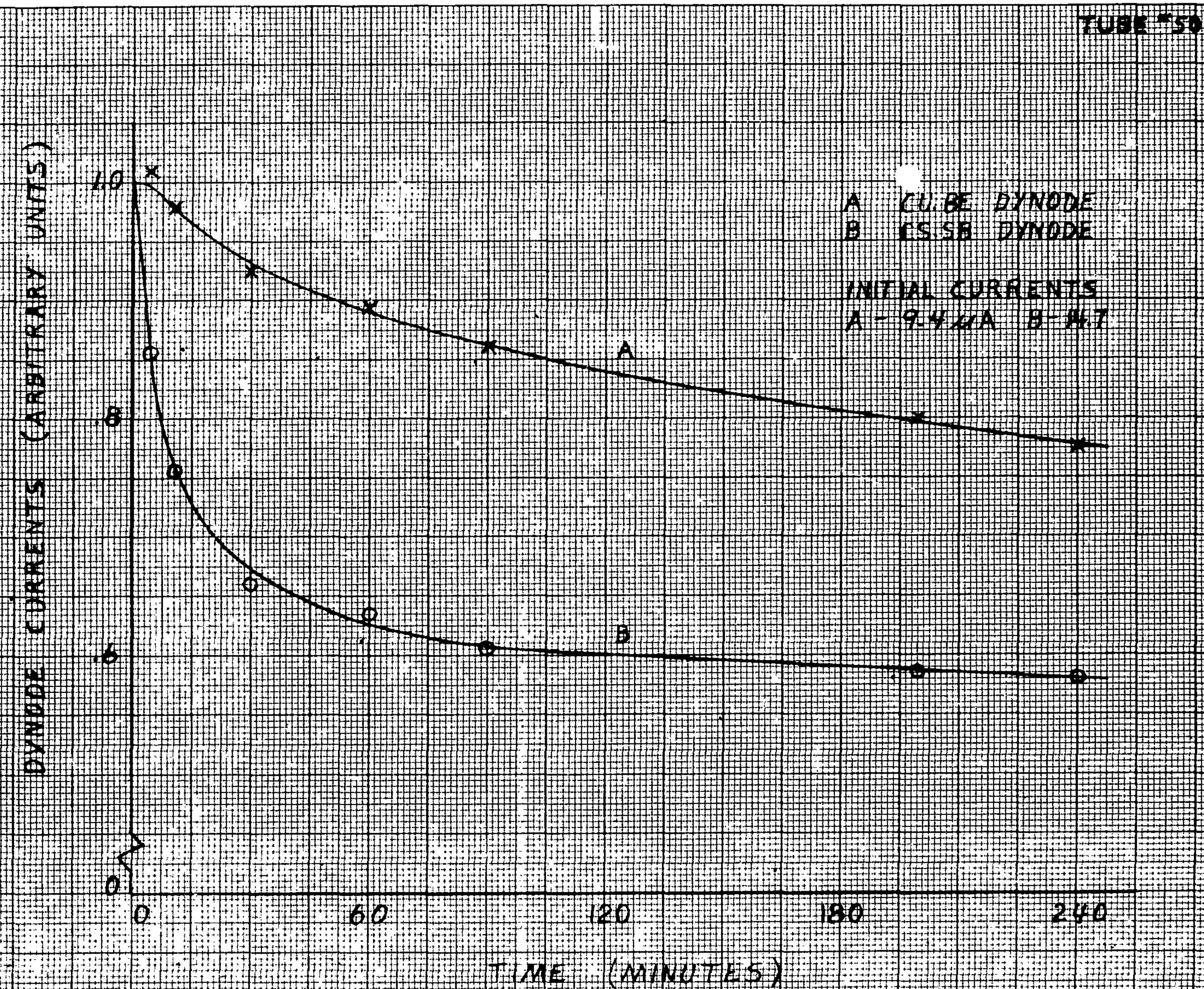


Fig. 18 - Comparison of Stability Characteristics of a CuBe and a CsSb Dynode in the Single-Stage Tube (C-7290) Before and After Baking and Aging.

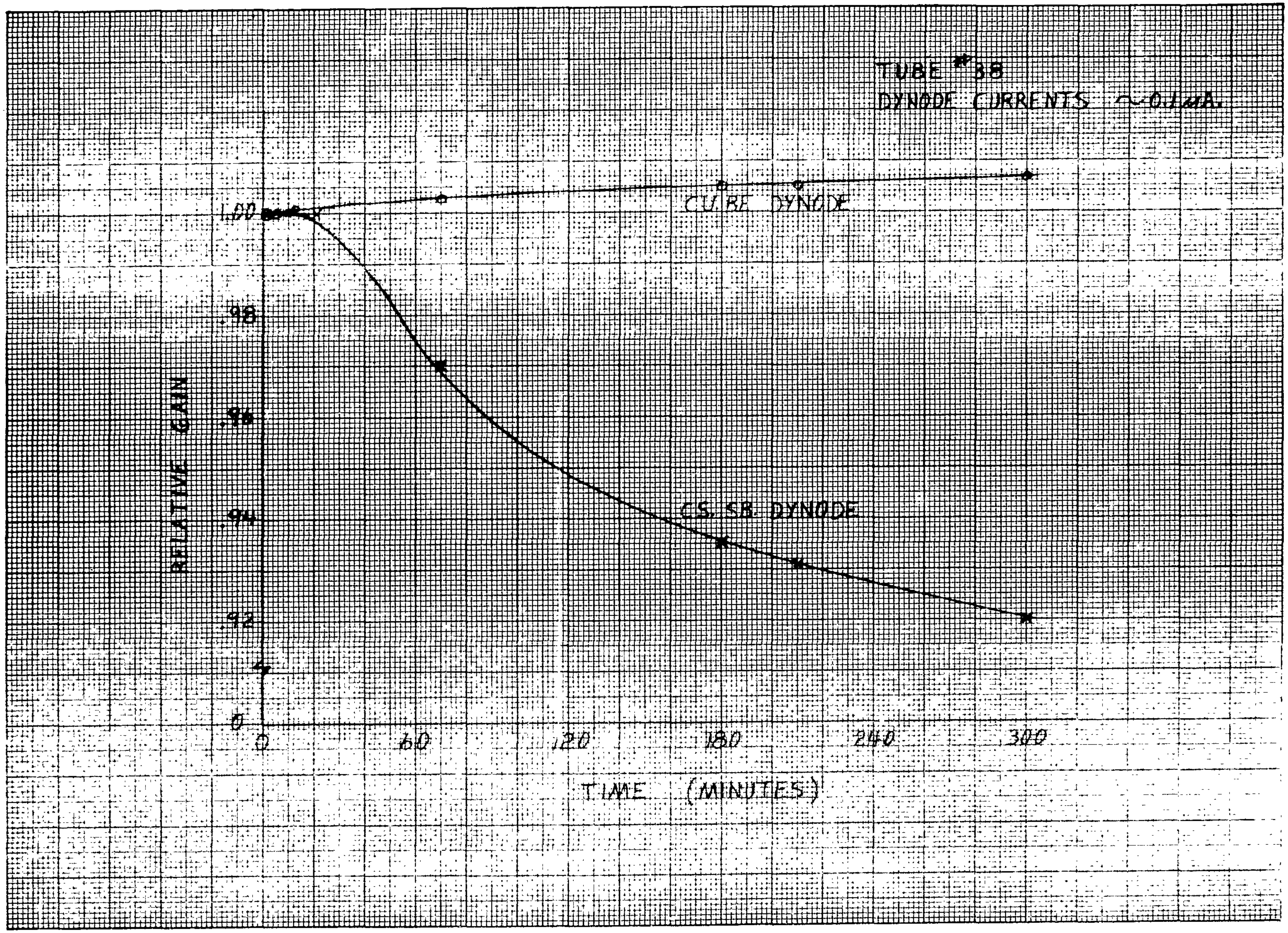


Fig. 19 - Comparison of Stability Characteristics of CuBe and Cs Sb Dynodes in the Single-stage Tube (C-7290)

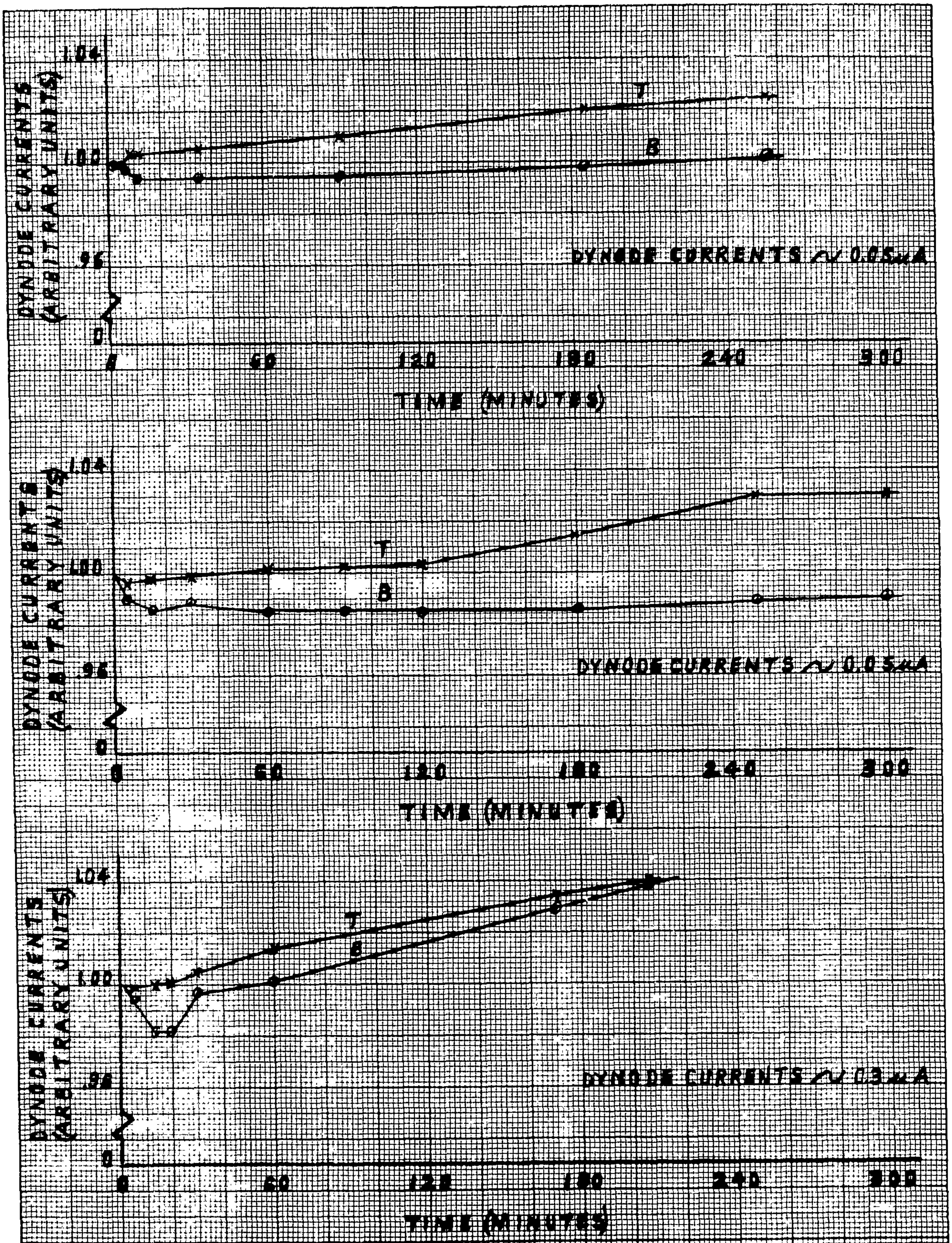


Fig. 20 - Stability Characteristics from Three Tests of a Single-Stage Test with CuBe Dynodes. The tests were Made at 90 Volts. The Top and Bottom Dynodes are Marked with a T and B, Respectively

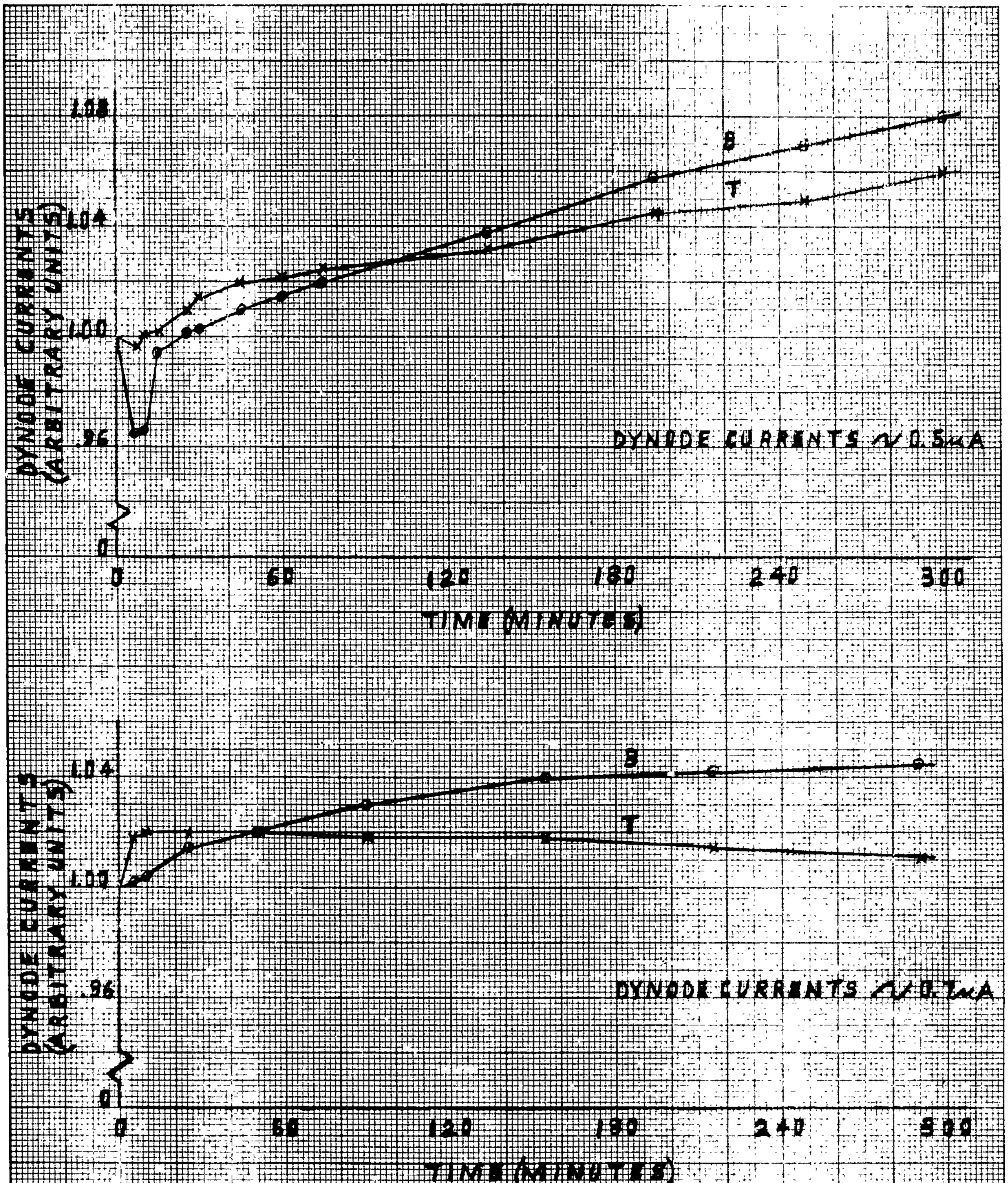


Fig. 21 - Stability Characteristics of Two CuBe Dynodes in a Single-Stage Tube Before and After Aging. The Top Dynode (T) was aged at 50 Volts and the Bottom (B) at 100 Volts.

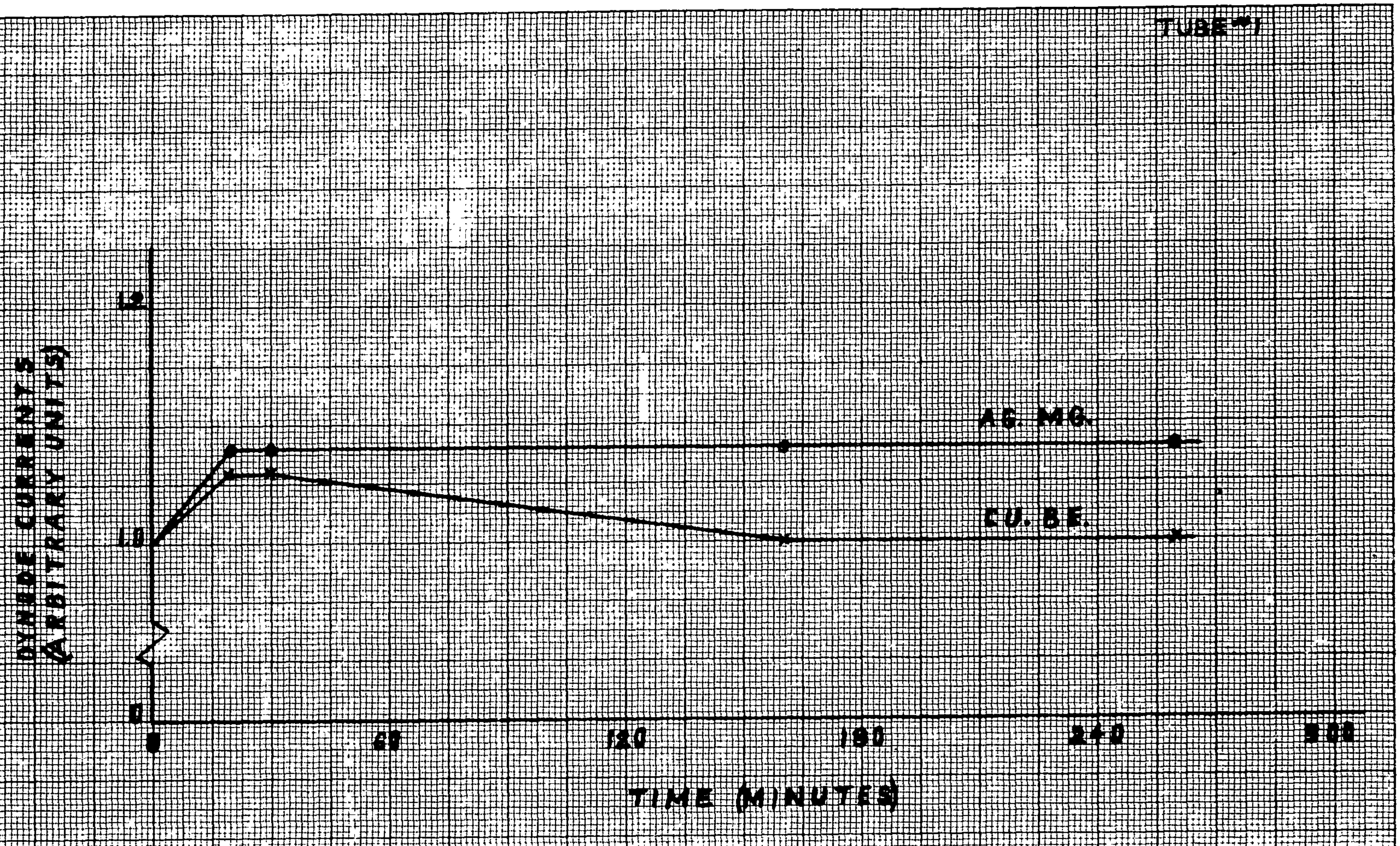


Fig. 22 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

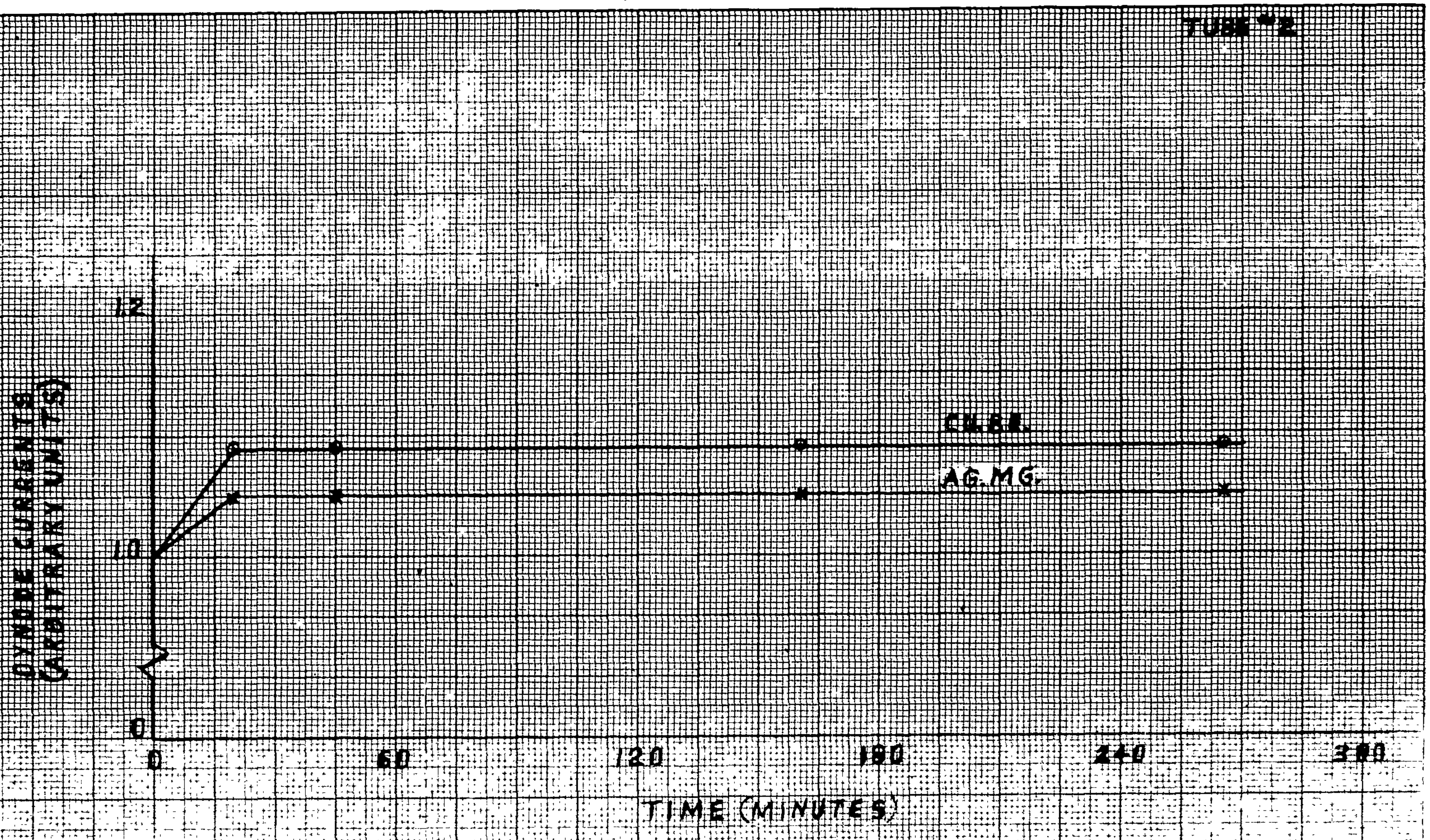


Fig. 23 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

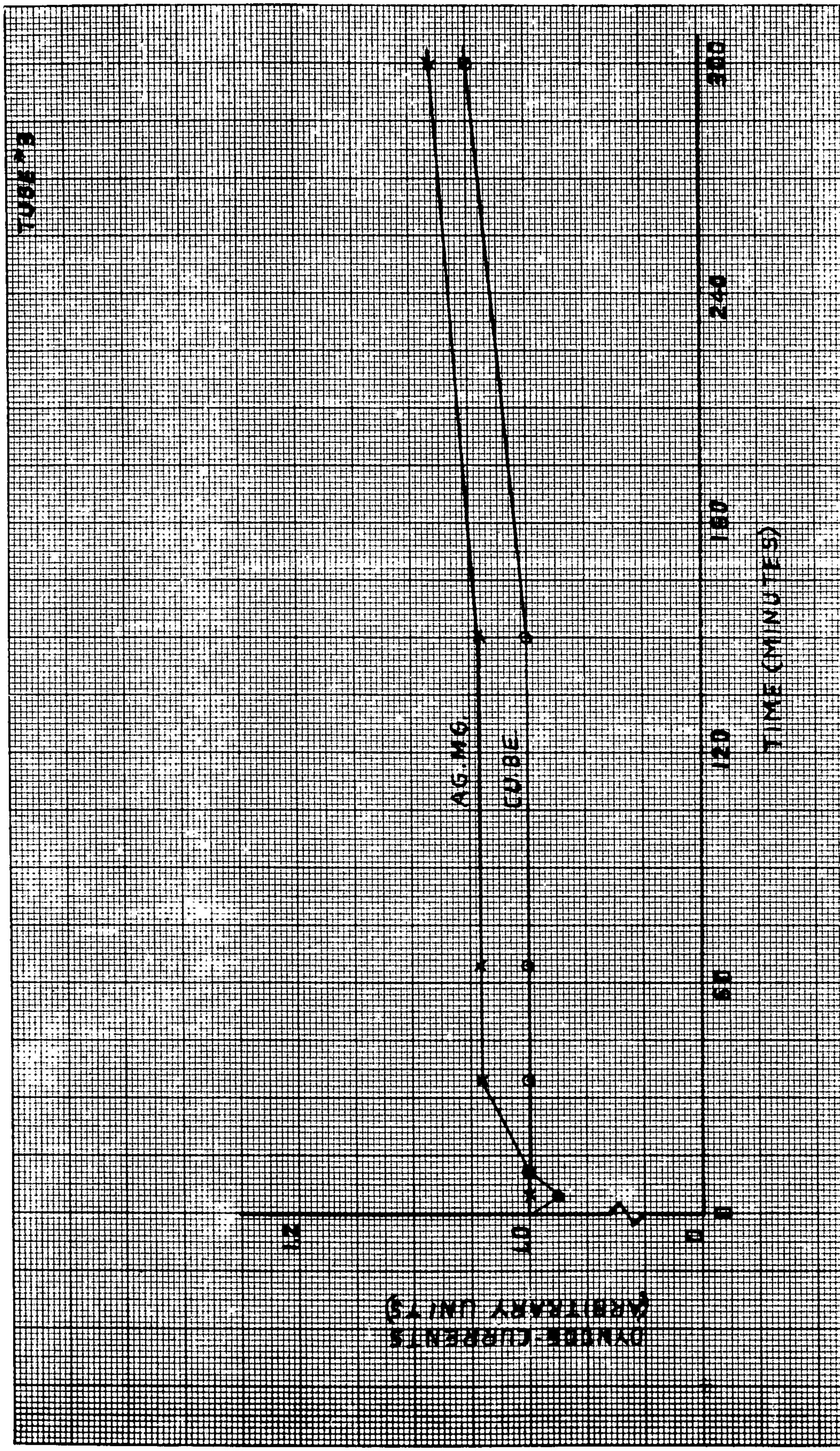


Fig. 24 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

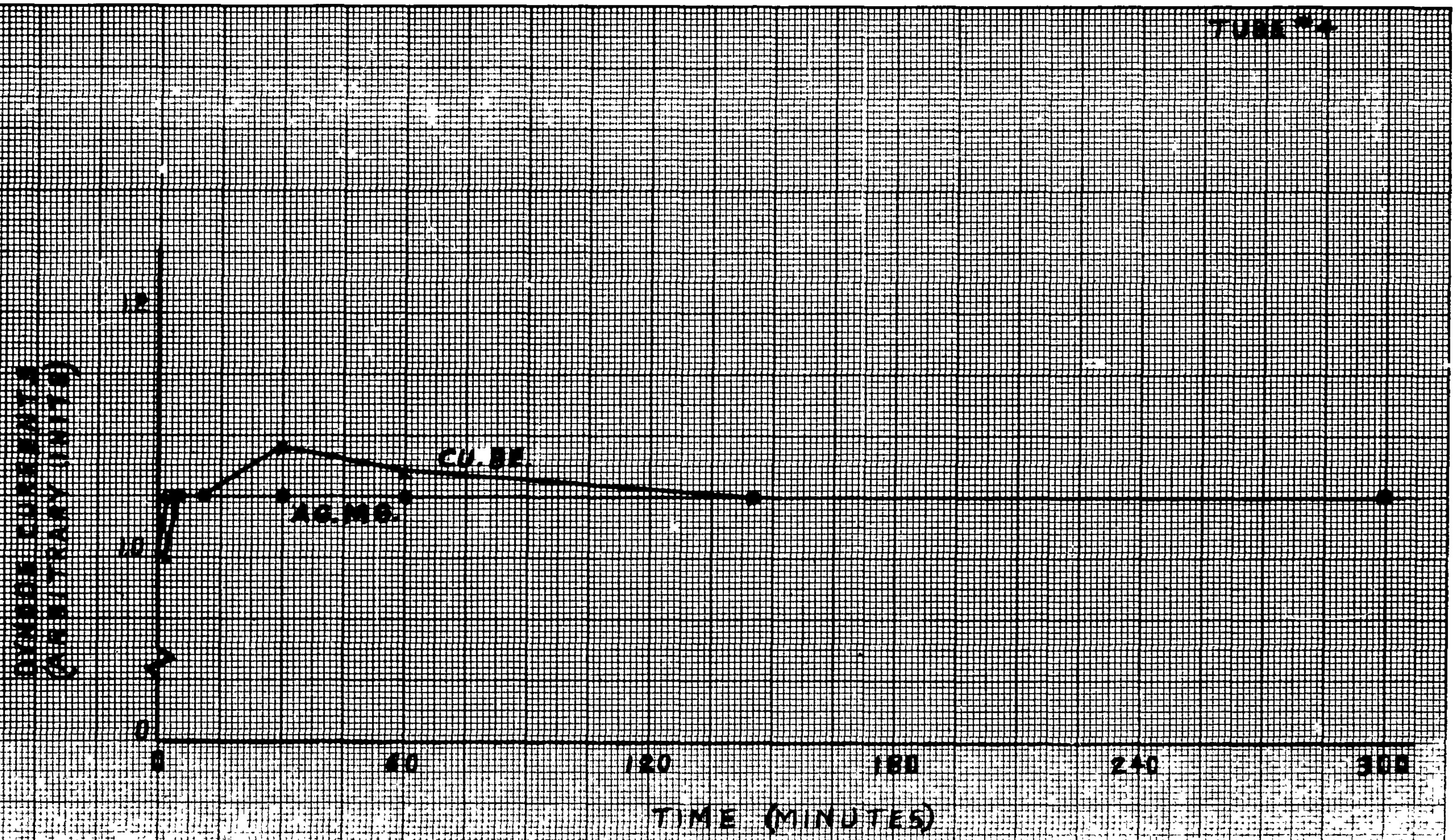


FIG. 25 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

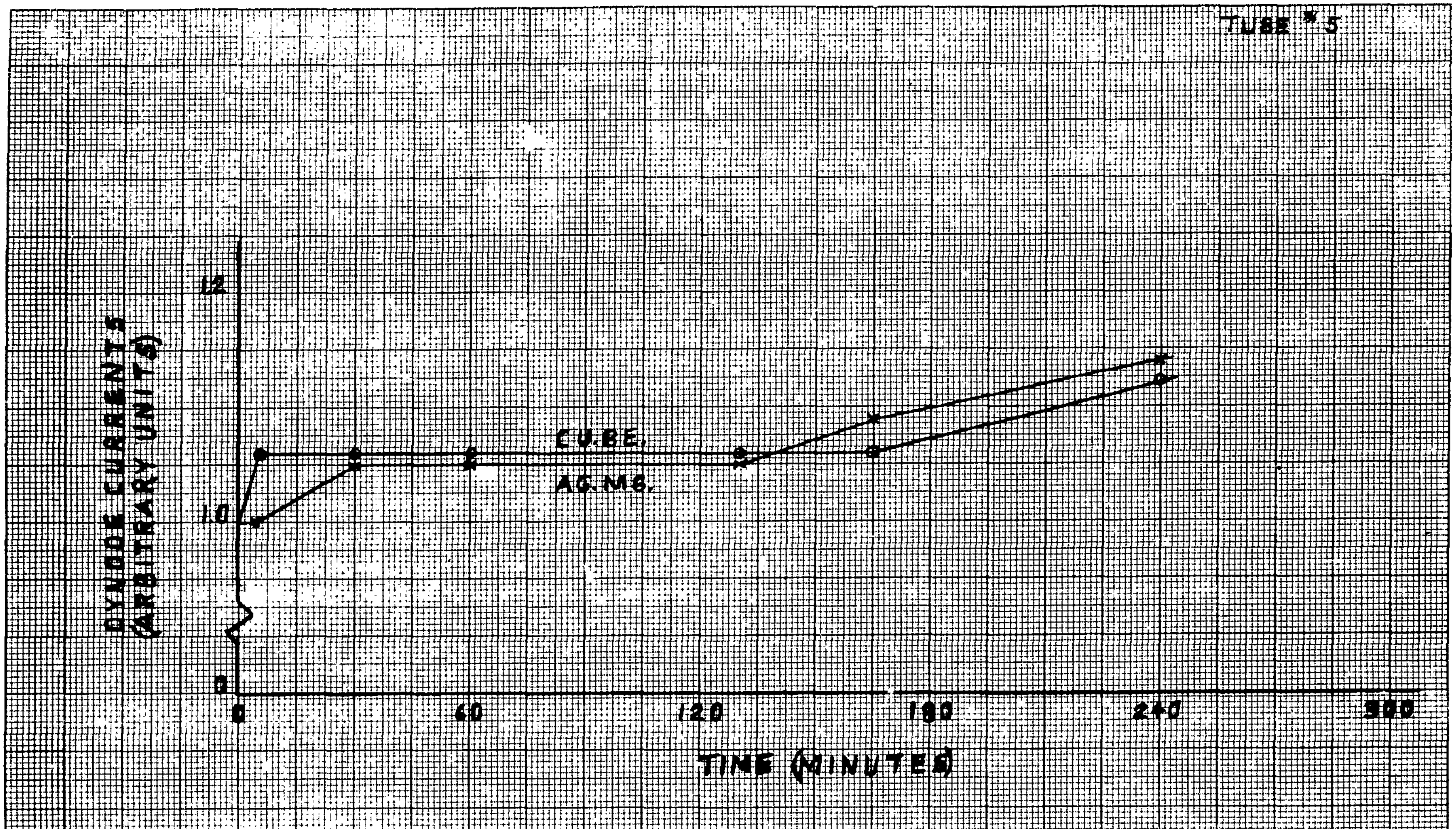


Fig. 26 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

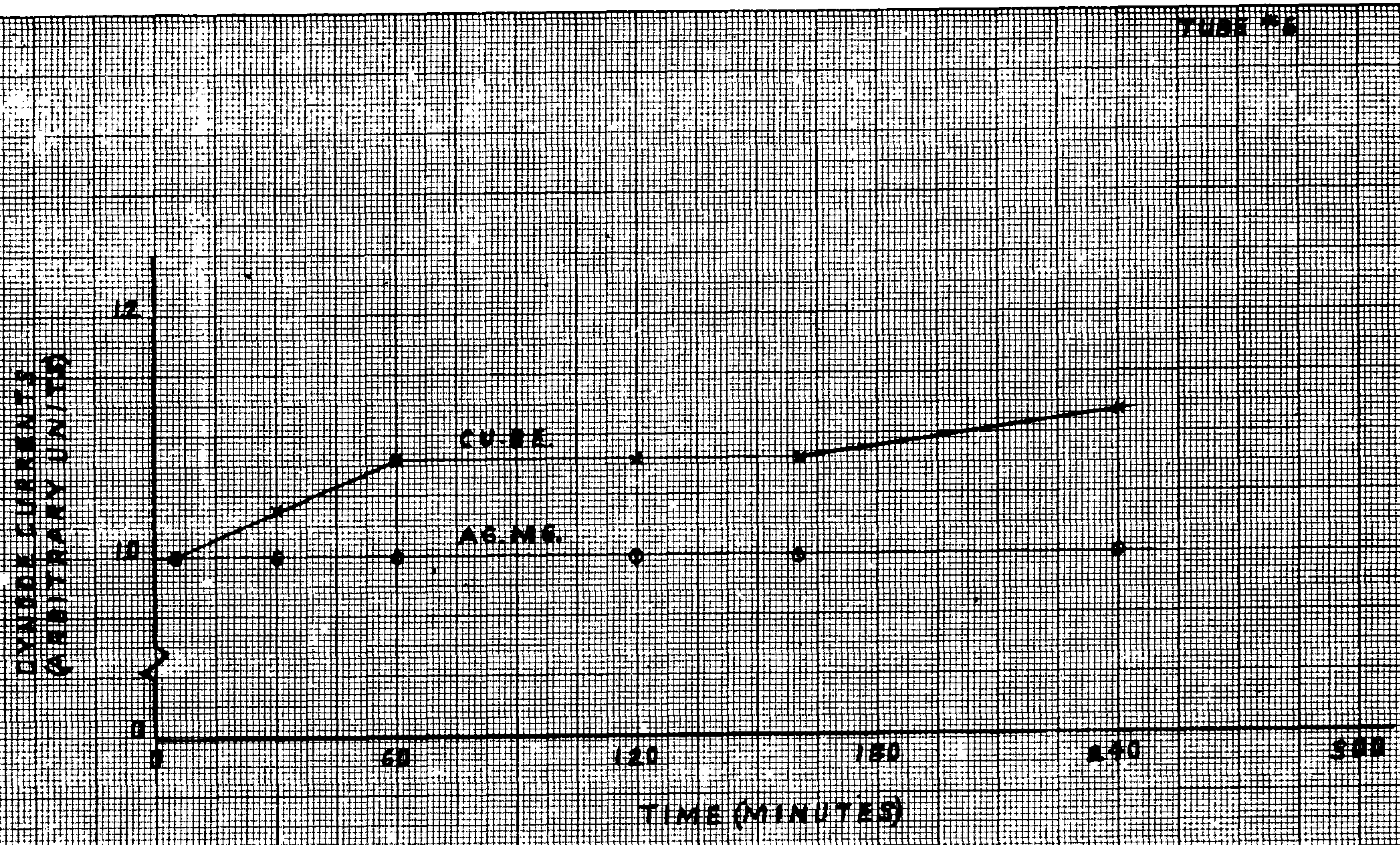


Fig. 27 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

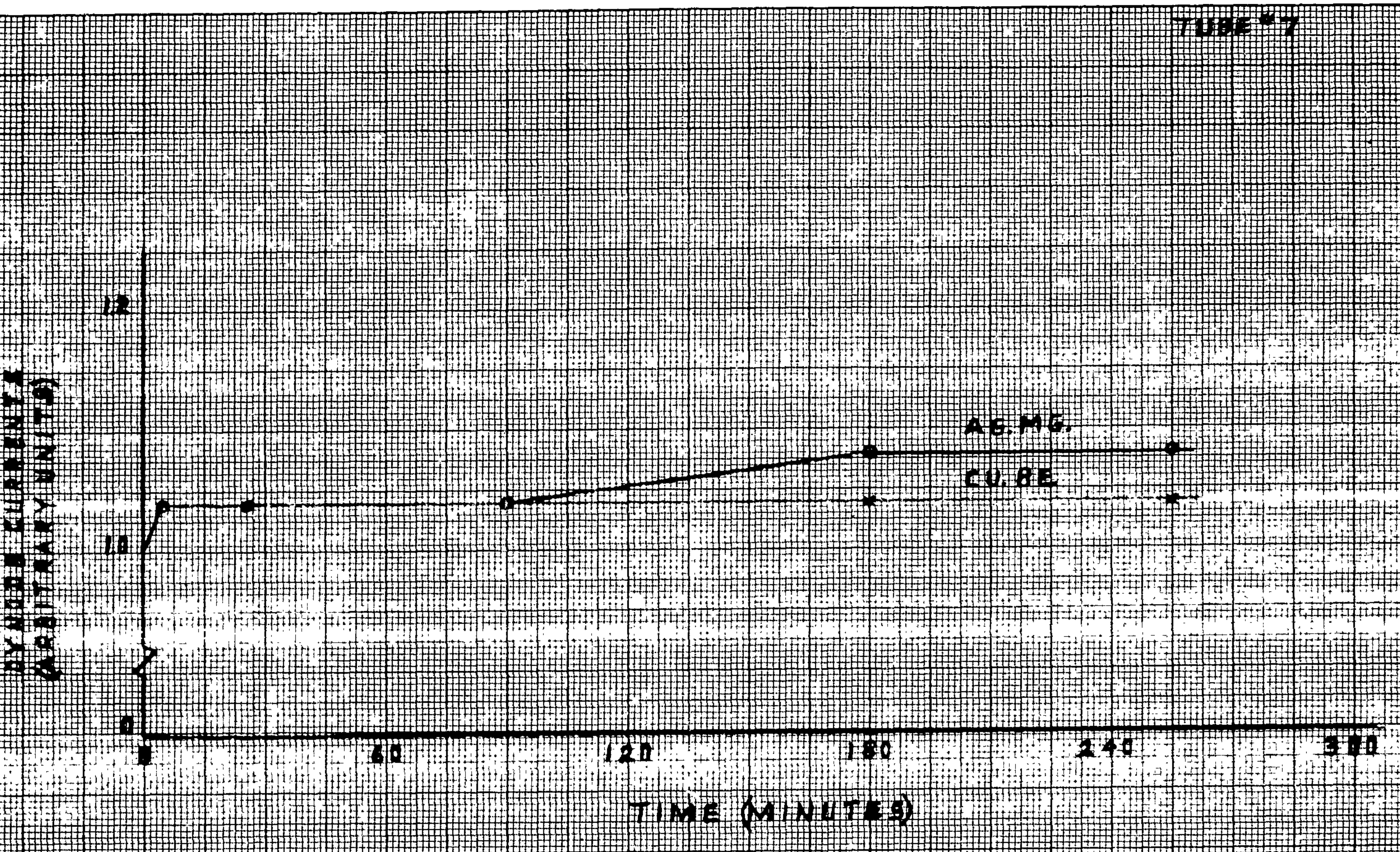


Fig. 28 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

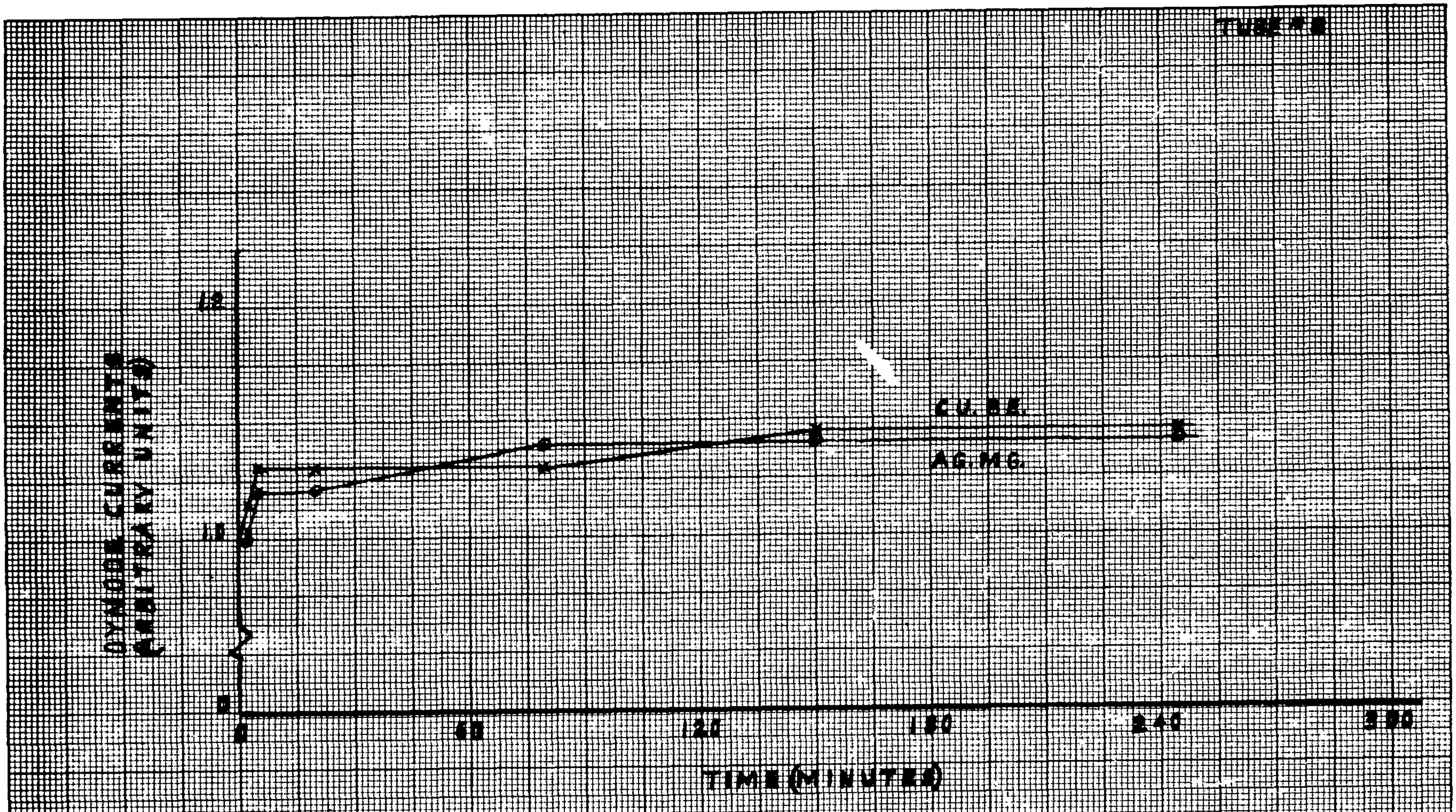


Fig. 29 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

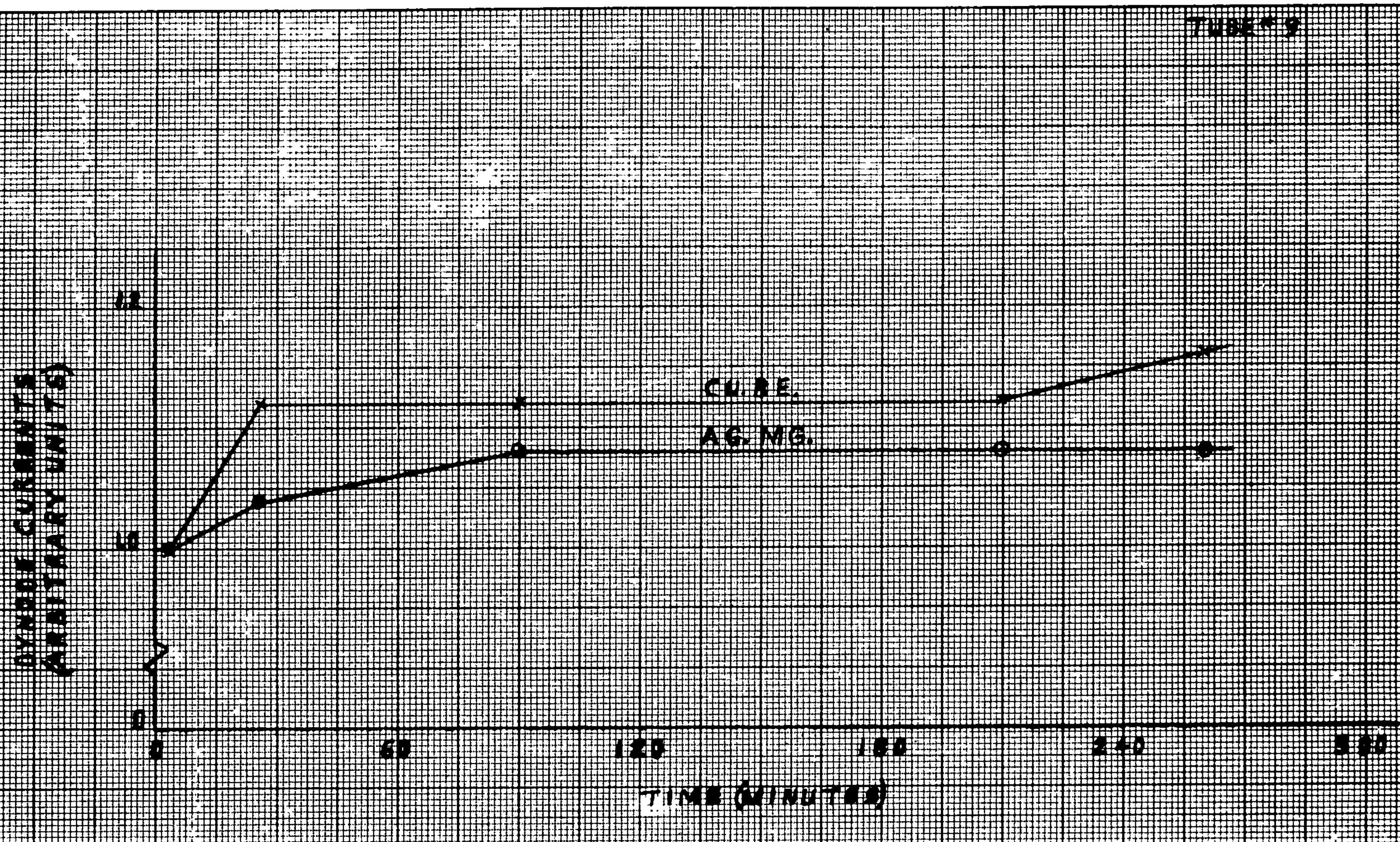


Fig. 30 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

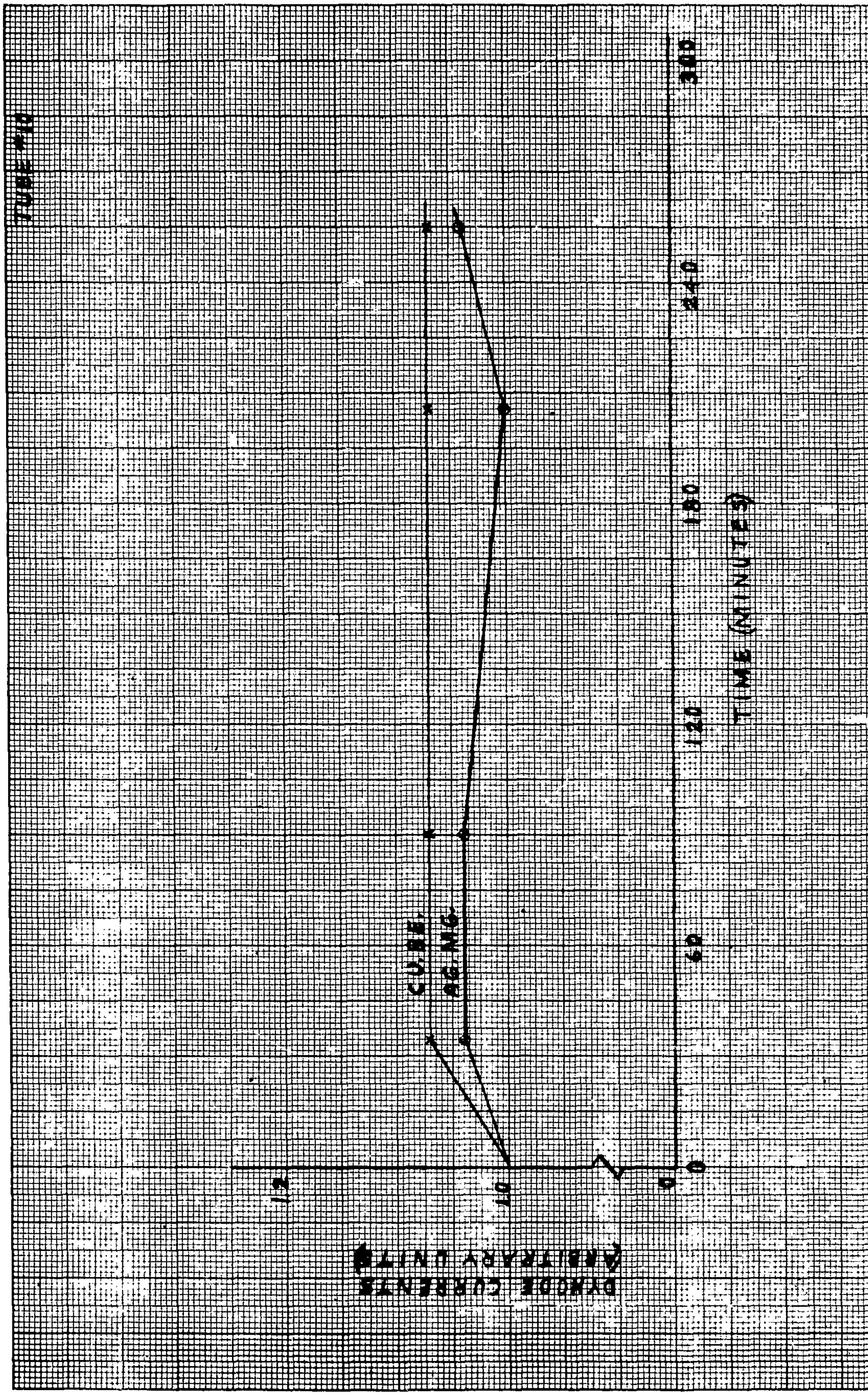


Fig. 31 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

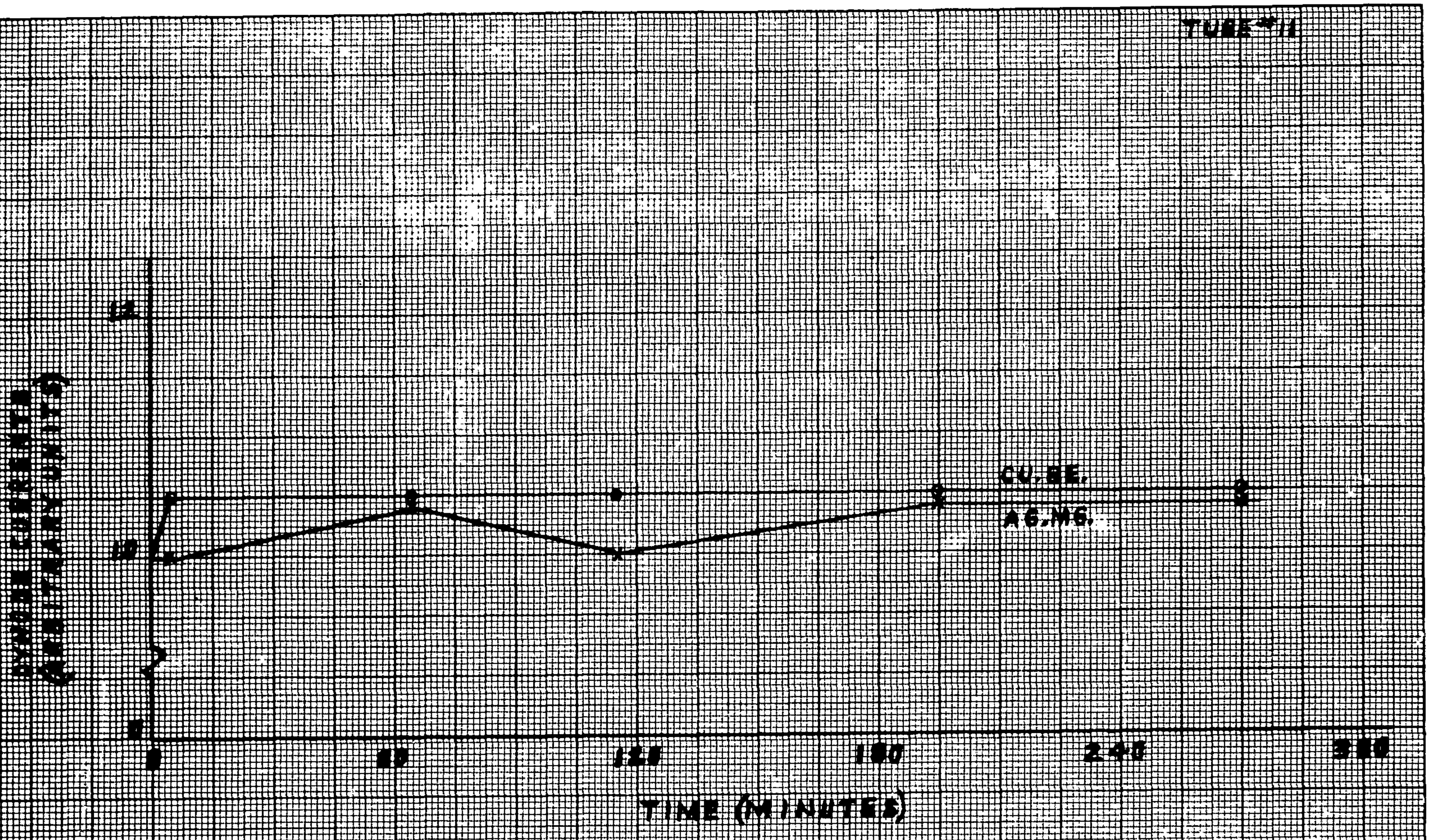


Fig. 32 - Stability Characteristics of a AgMg and a CuBe Dynode in the Single-Stage Tube

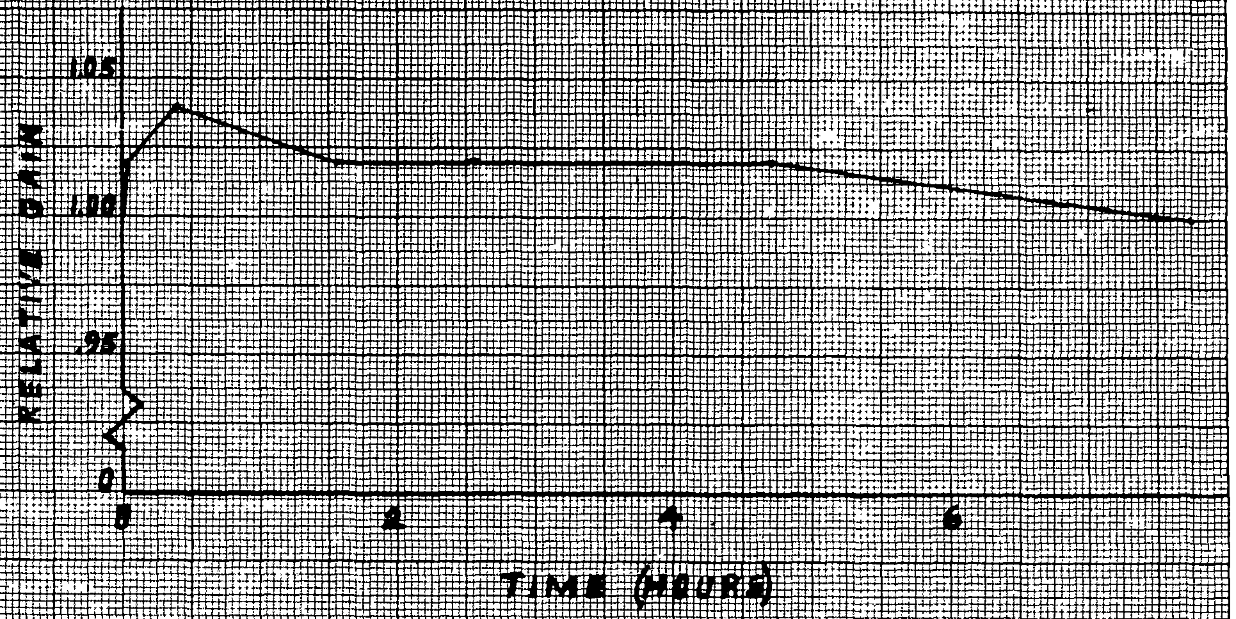


Fig. 33 – Stability Characterists of a K_3Sb Secondary Emitter Surface. The Primary Current Density was about 15 µA/cm² with an Energy of 90 ev.

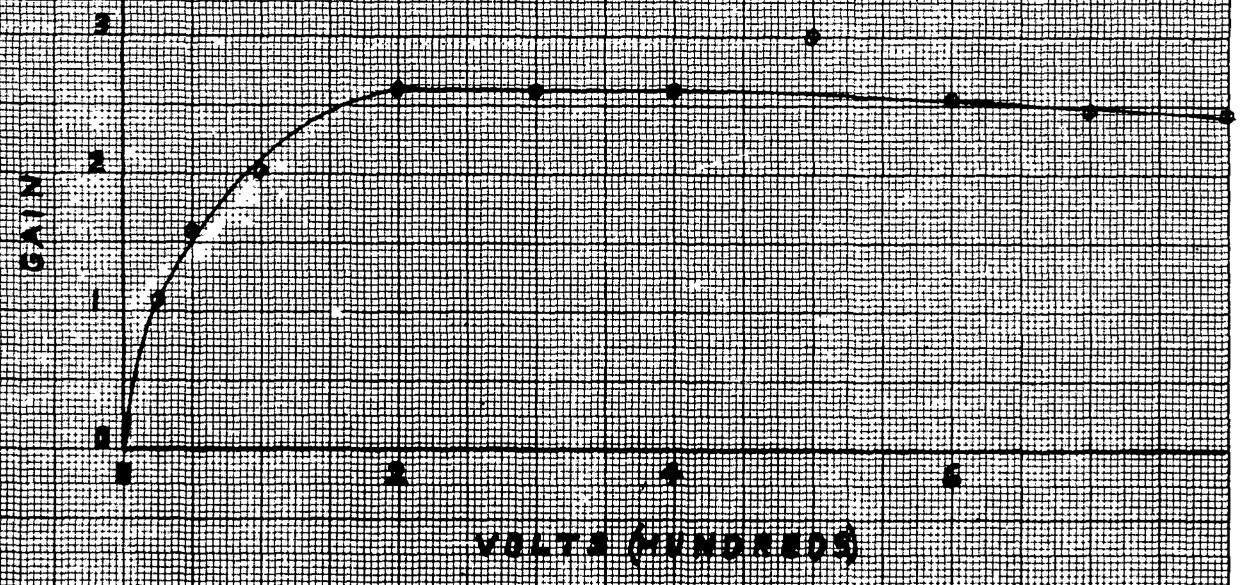


Fig. 34 – Gain Curve for a K_3Sb Secondary Emitter Surface

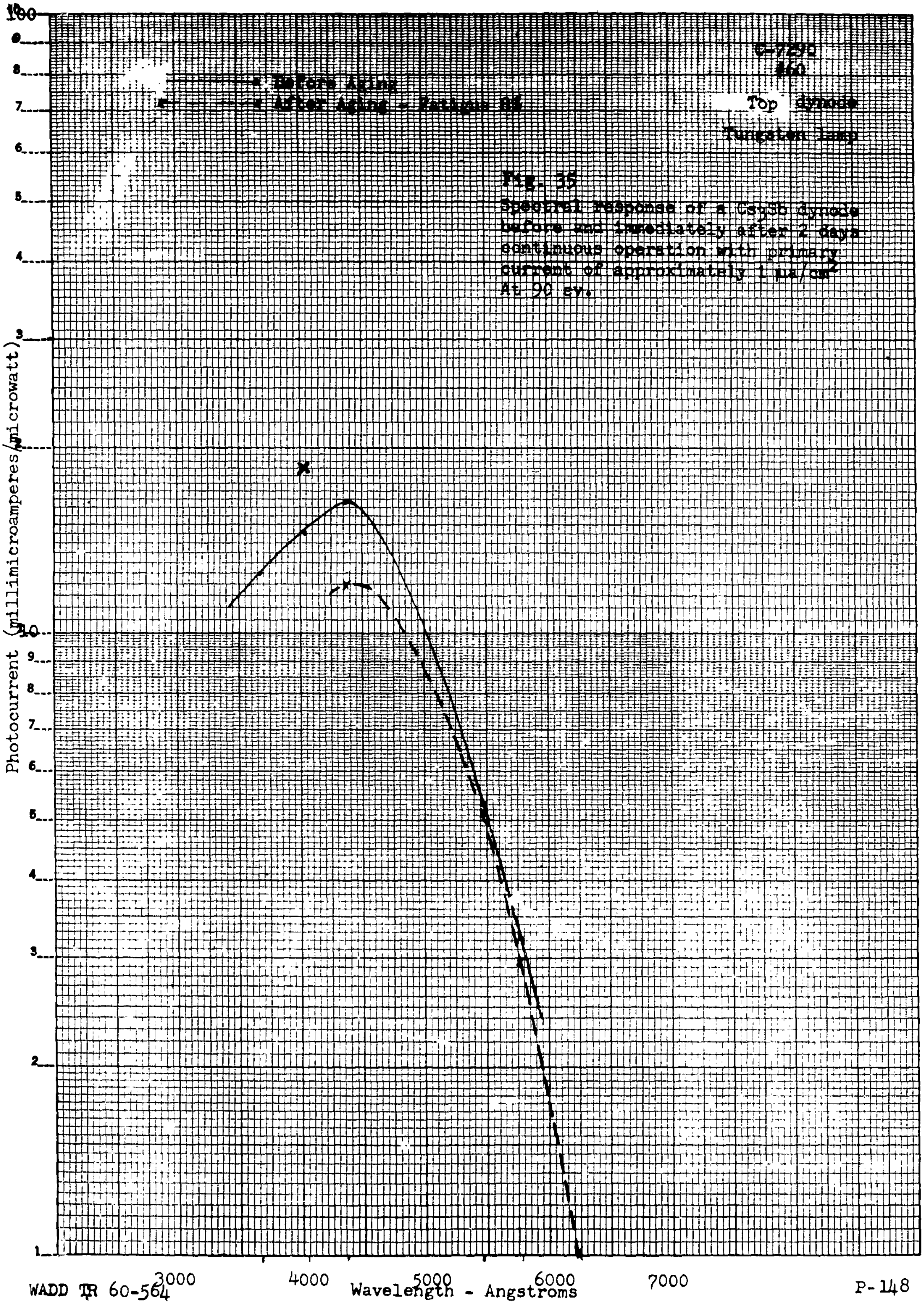
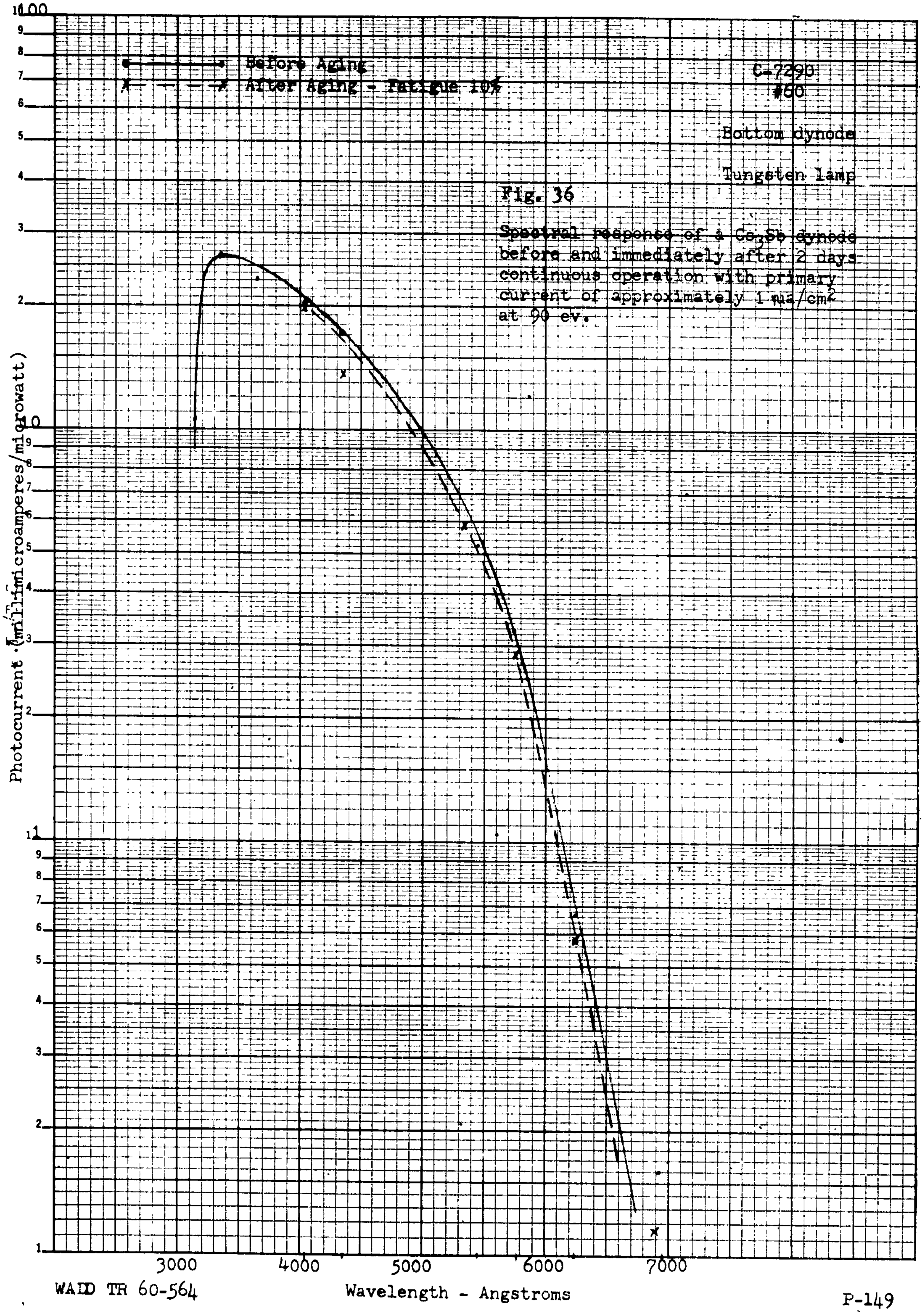


Fig. 35
Spectral response of a Cs_3Sb dynode before and immediately after 2 days continuous operation with primary current of approximately 1 μa/cm^2 At 90 ev.


Before Aging
After Aging - Fatigue 10%
C-7290
#80
Bottom dynode
Tungsten lamp
Fig. 36
Spectral responce of a Cs_3Sb dynode before and immediately after 2 days continuous operation with primary current of approximately 1 ma/cm^2 at 90 ev.
Photocurrent (millimicroamperes/microwatt)
3000
4000
5000
6000
7000
Wavelength - Angstroms

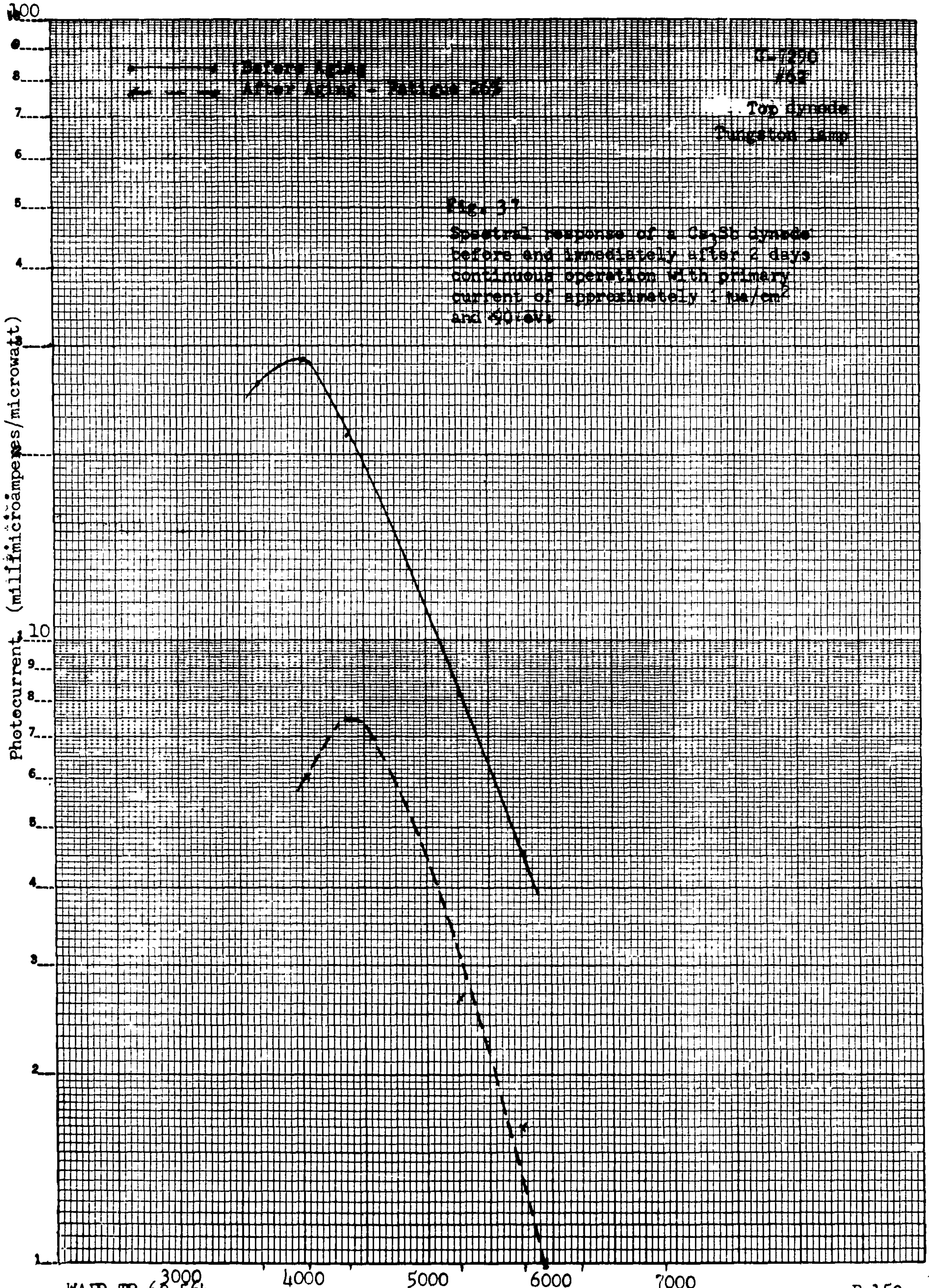


Fig. 37
Spectral response of a Cs_3Sb dynode before and immediately after 2 days continuous operation with primary current of approximately 1 ua/cm^2 and 40 eV.

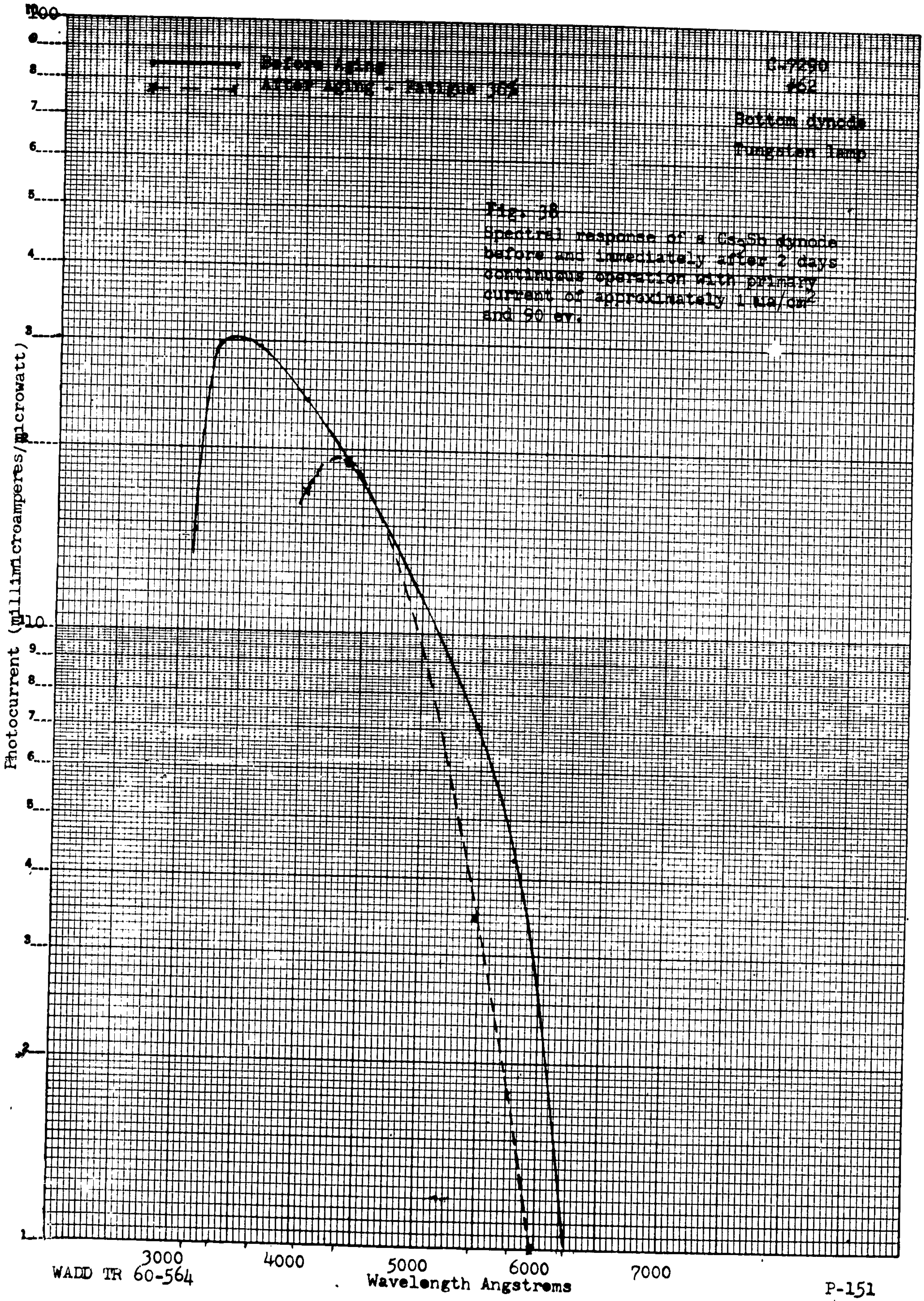


Fig. 38
Spectral response of a Cs_3Sb dynode before and immediately after 2 days continuous operation with primary current of approximately 1 ua/cm^2 and 90 ev.

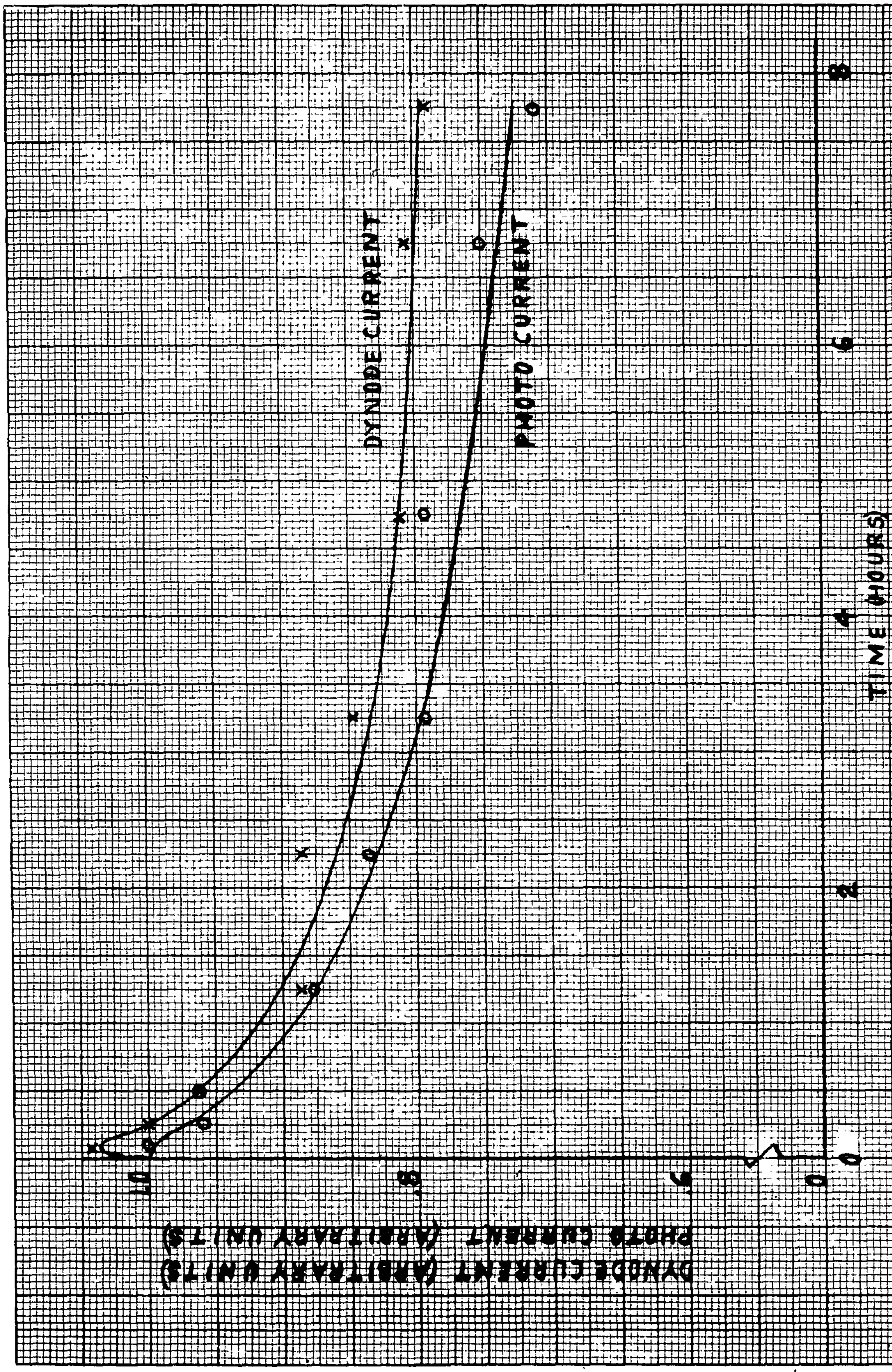


Fig. 39 - Decrease of Photoemission of a Cs_3Sb Surface Caused by Fatigue in Secondary Emission

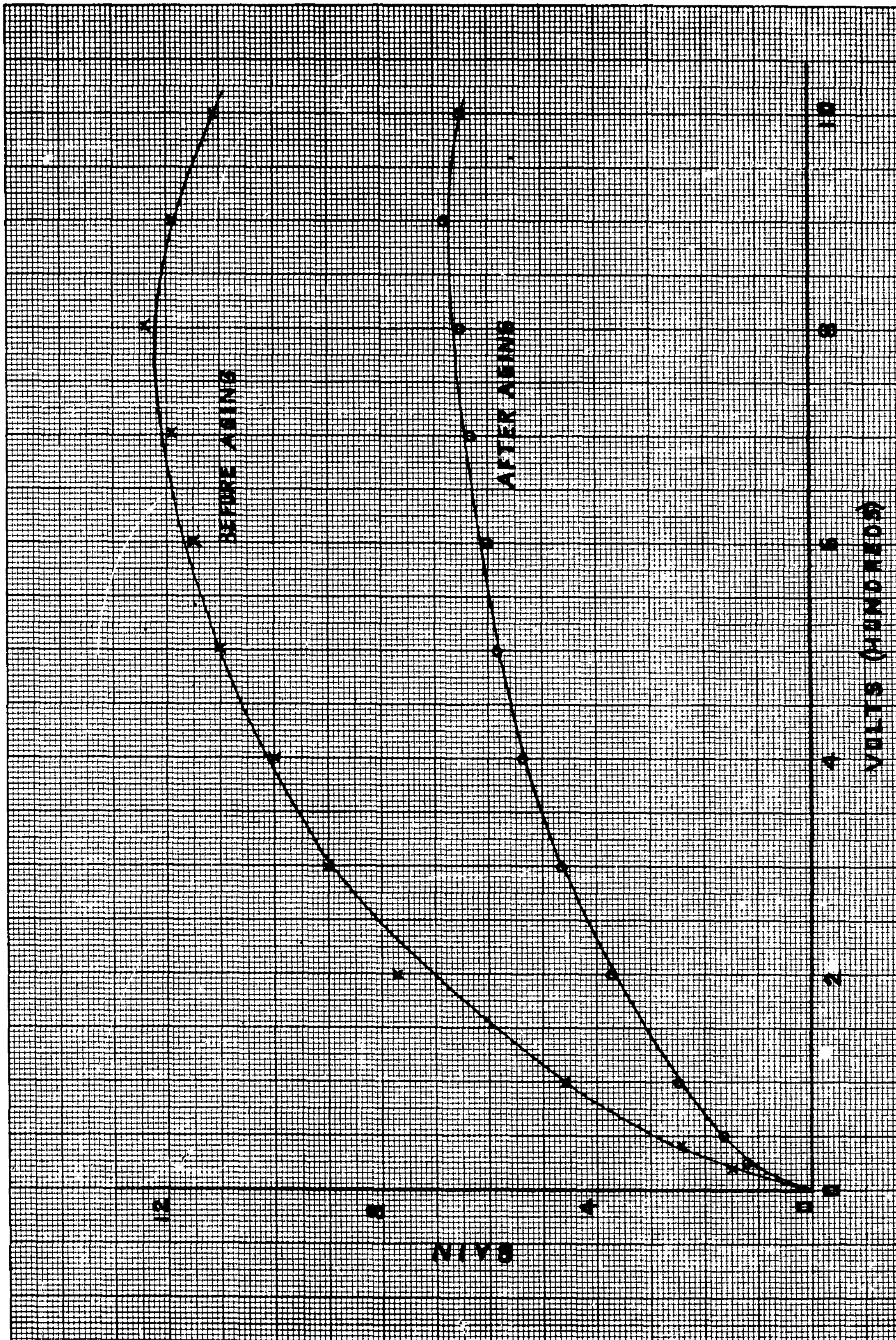


Fig. 40 - Gain Vs. Voltage of a Cs_3Sb Secondary Emitter Surface Before and After Aging.

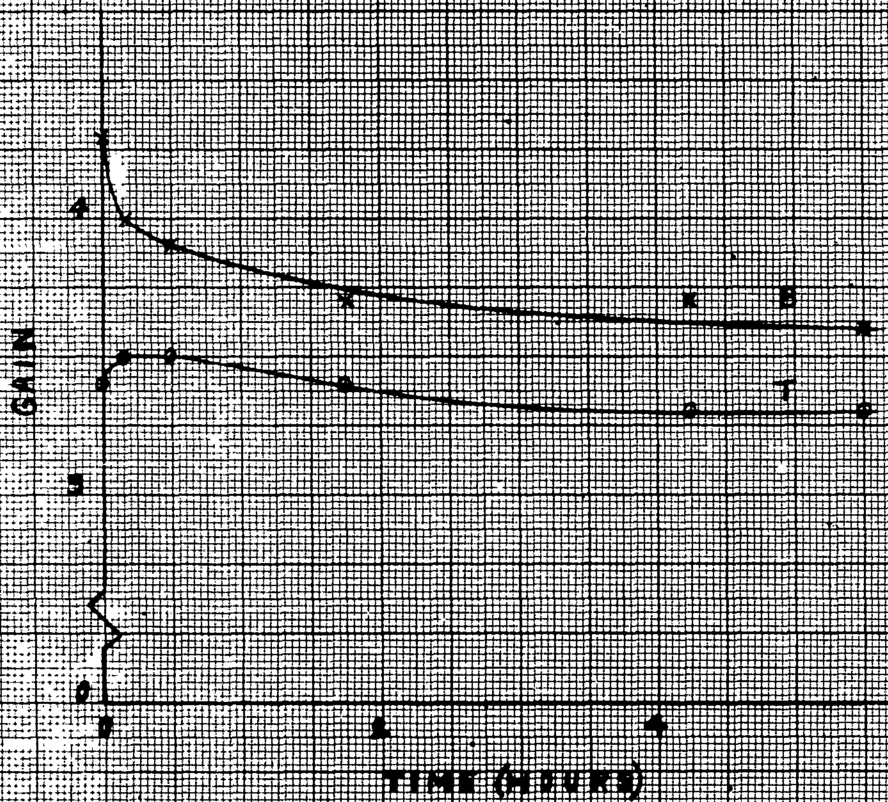


Fig. 41 - Stability Characteristics of a Single-Stage Tube at -27° C. Initial Dynode Currents Were About 12 uA.

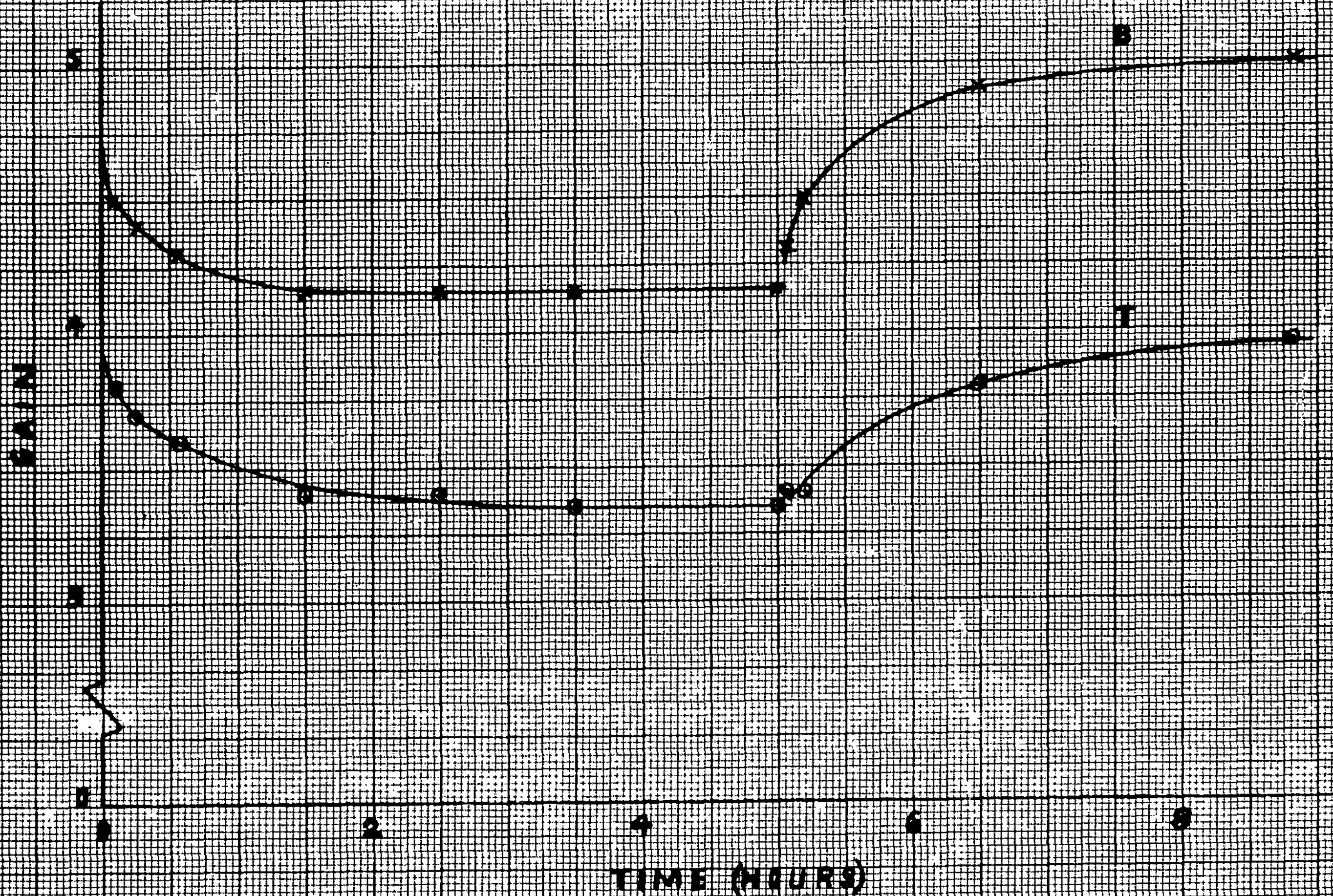


Fig. 42 - Stability Characteristics and Recovery of Cs_3Sb Surfaces in the Single-Stage Tube. The Initial Current for the Top (T) Dynode was 24.5 µA and the Initial Current for the Bottom (B) was 21 µA.

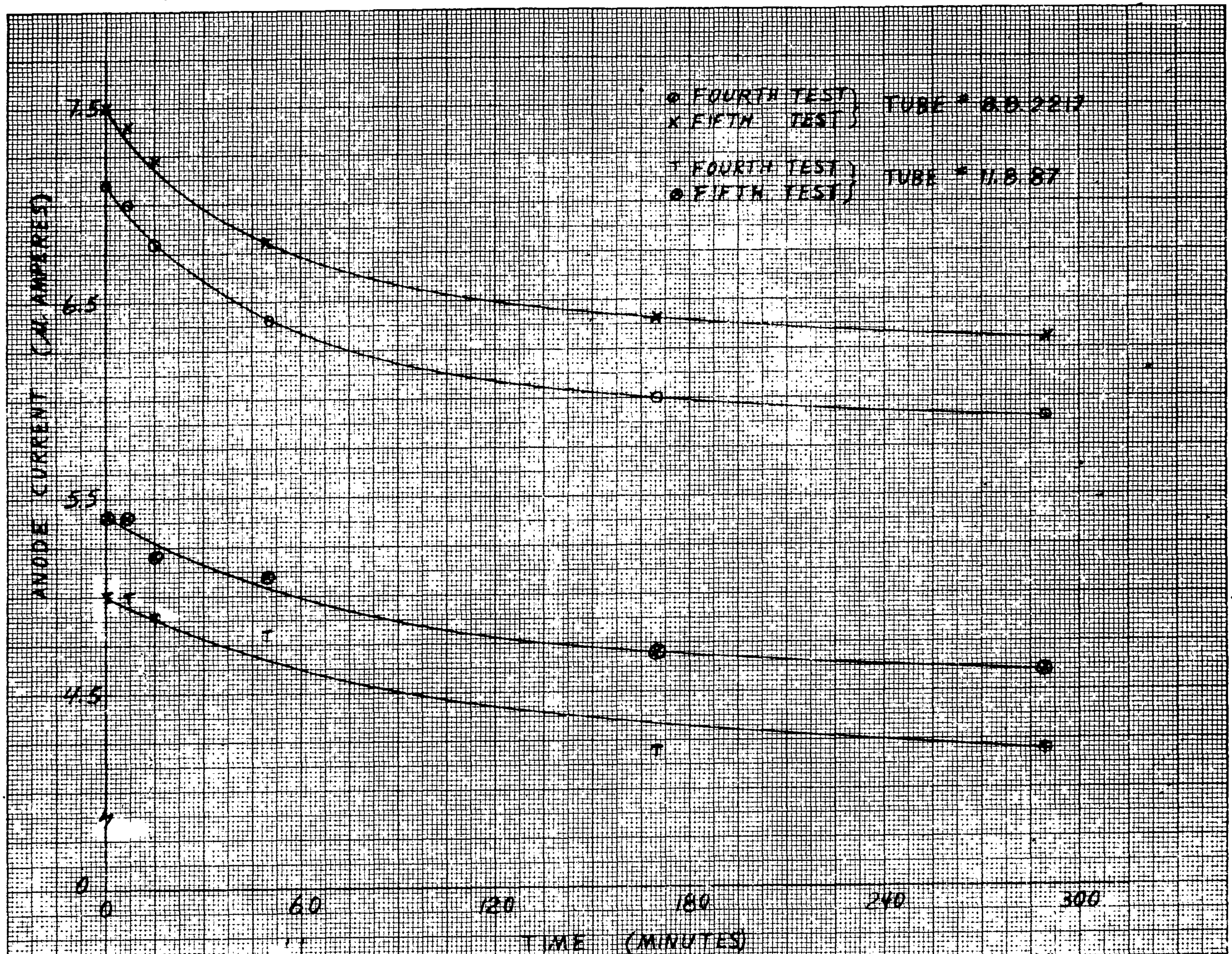


Fig. 81 - Stability Characteristics of 7029's Showing that Fatigue is Reproducible

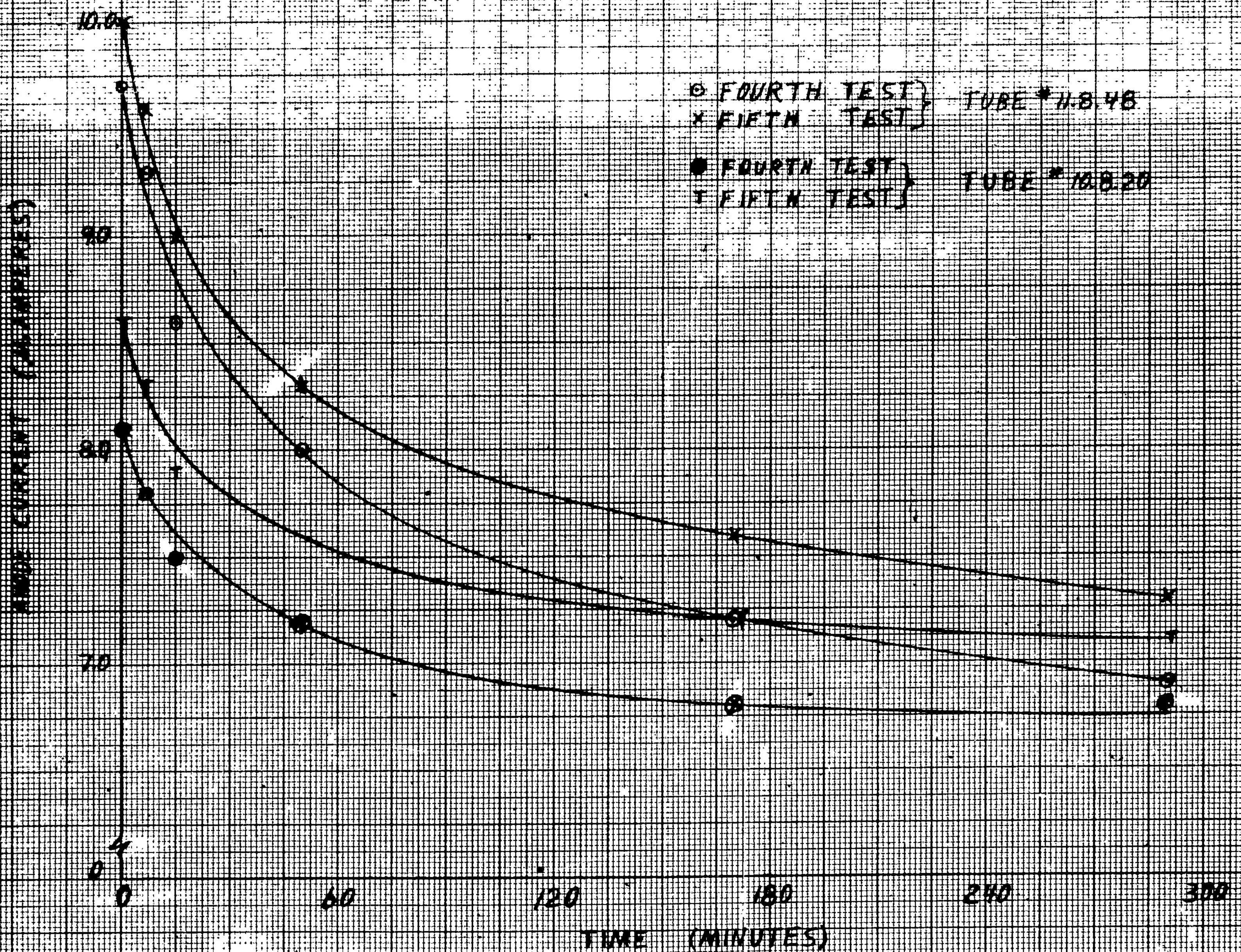


Fig. [illegible] - Stability Characteristics of 7029's Showing that Fatigue is Reproducible

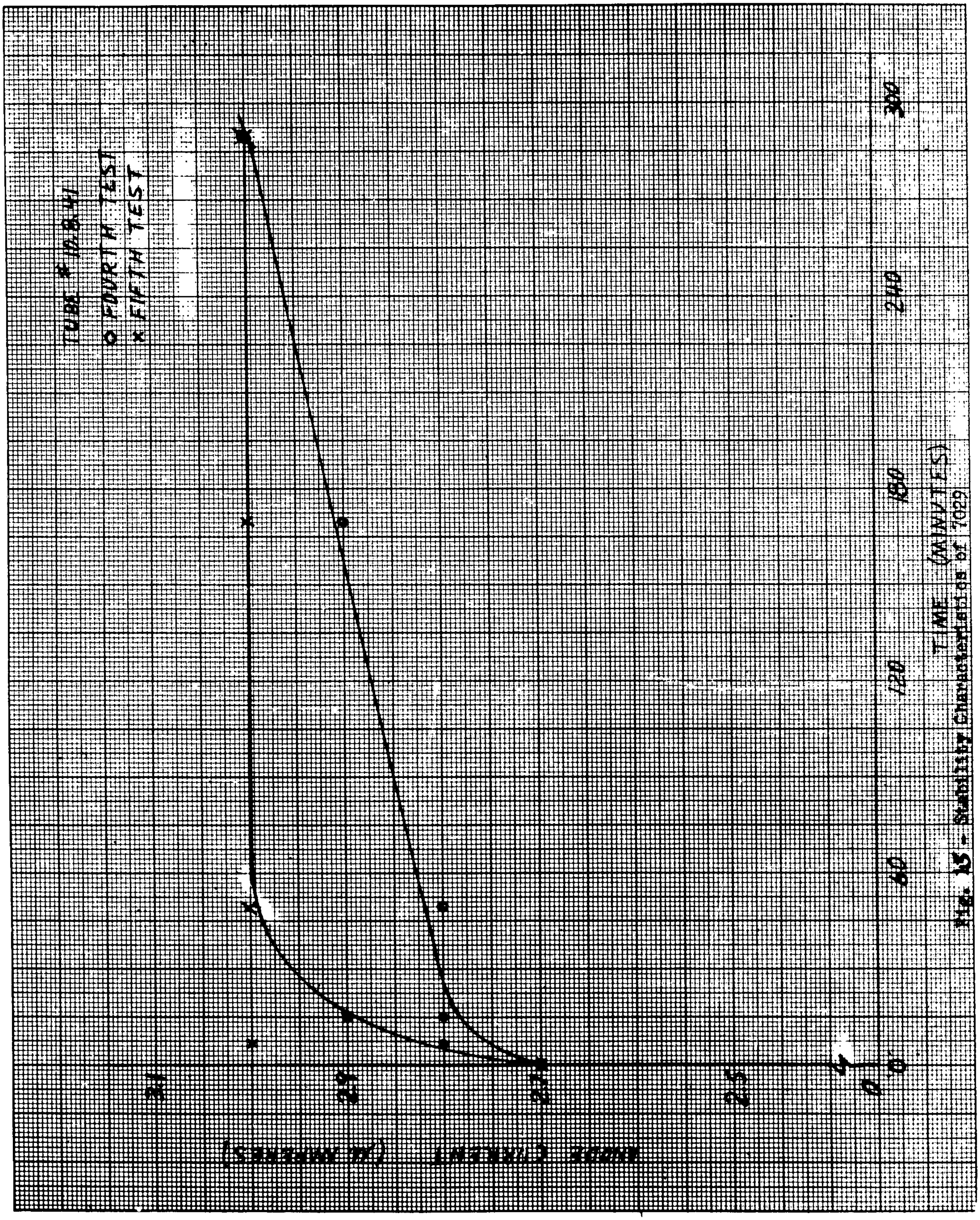


Fig. 15 - Stability Characteristics of 7029

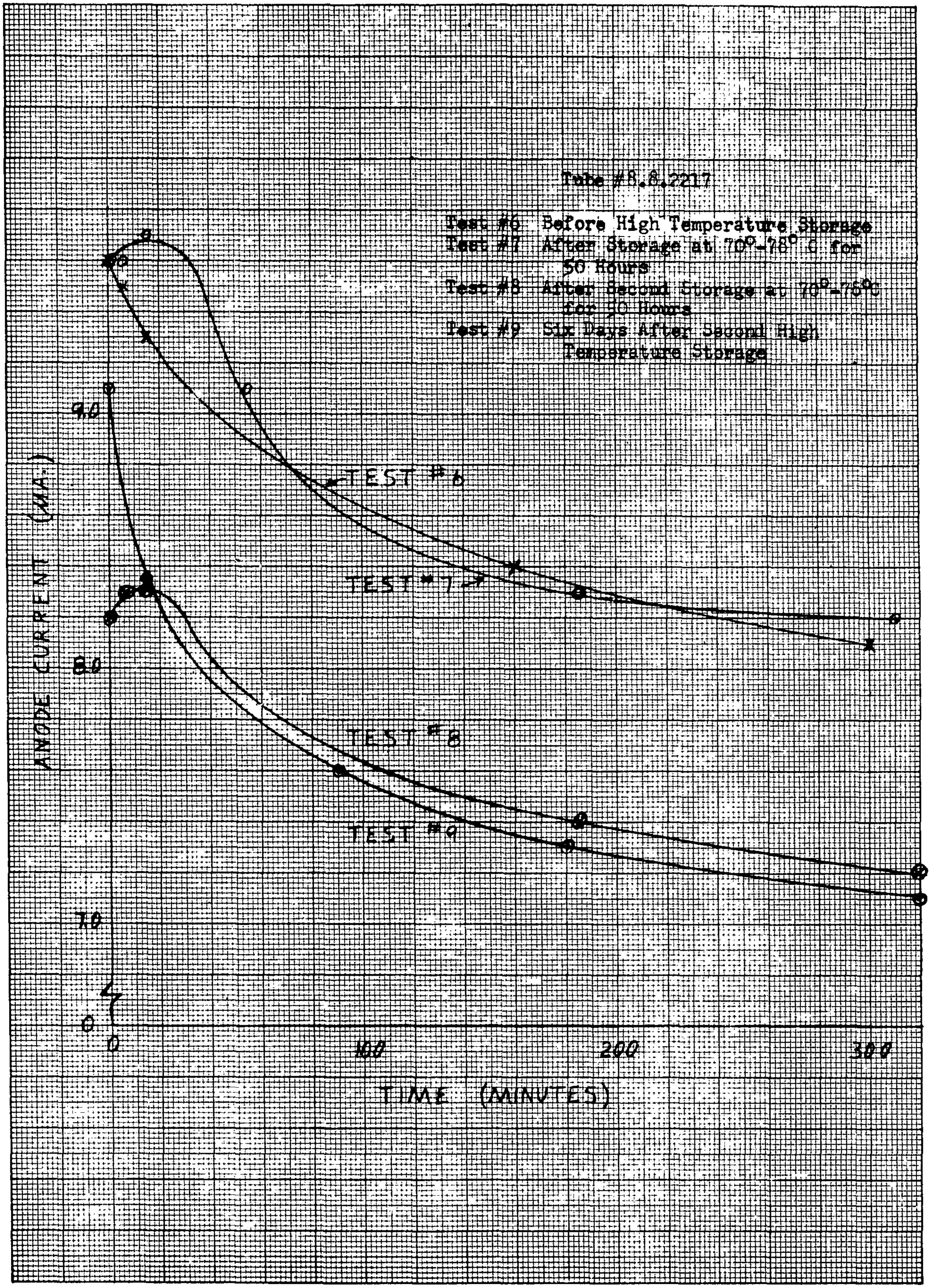


Fig. 46 - Effect of High Temperature Storage on 7029 Photomultiplier

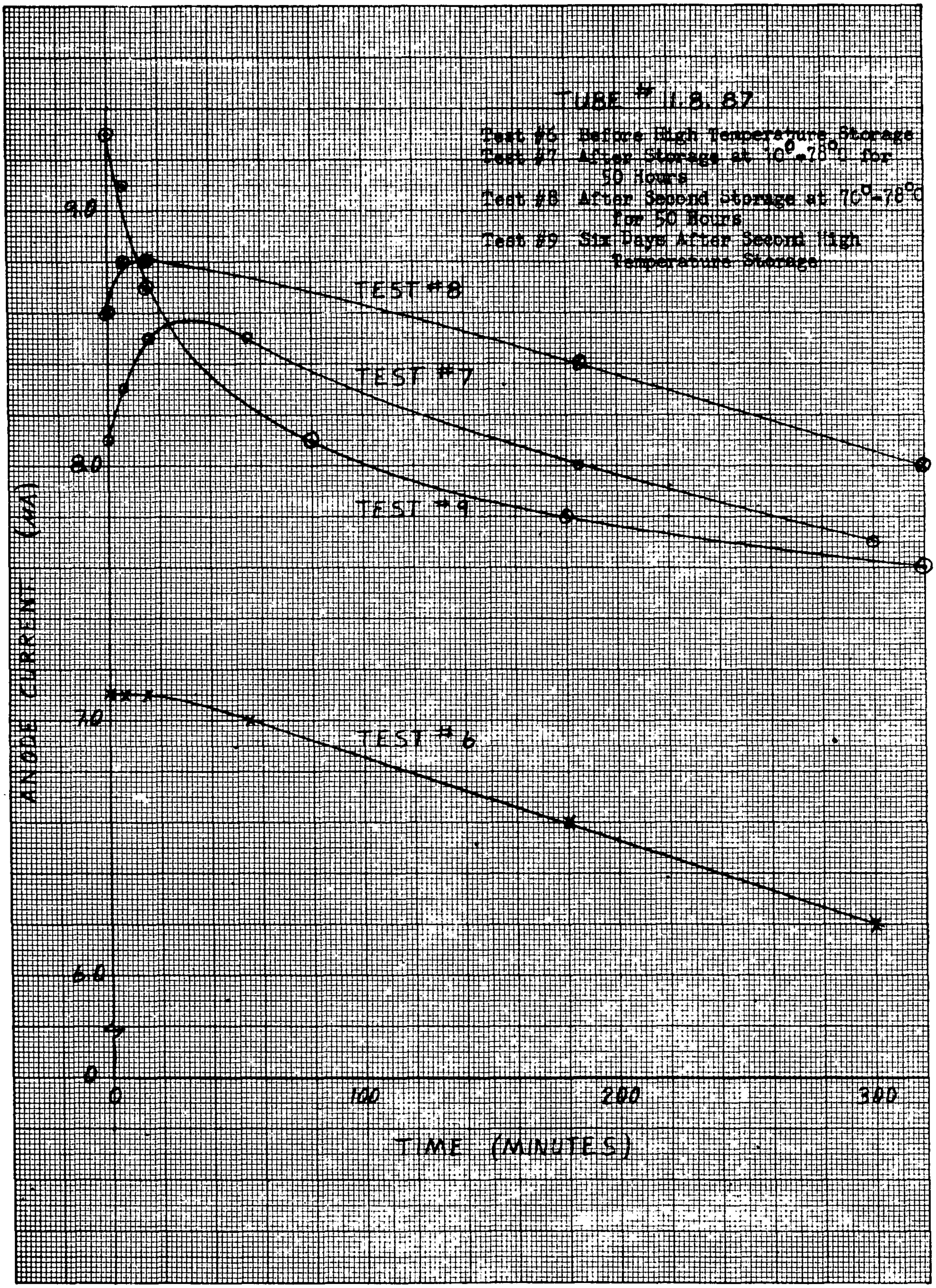


Fig. 47 - Effect of High Temperature Storage on 7029 Photomultipliers

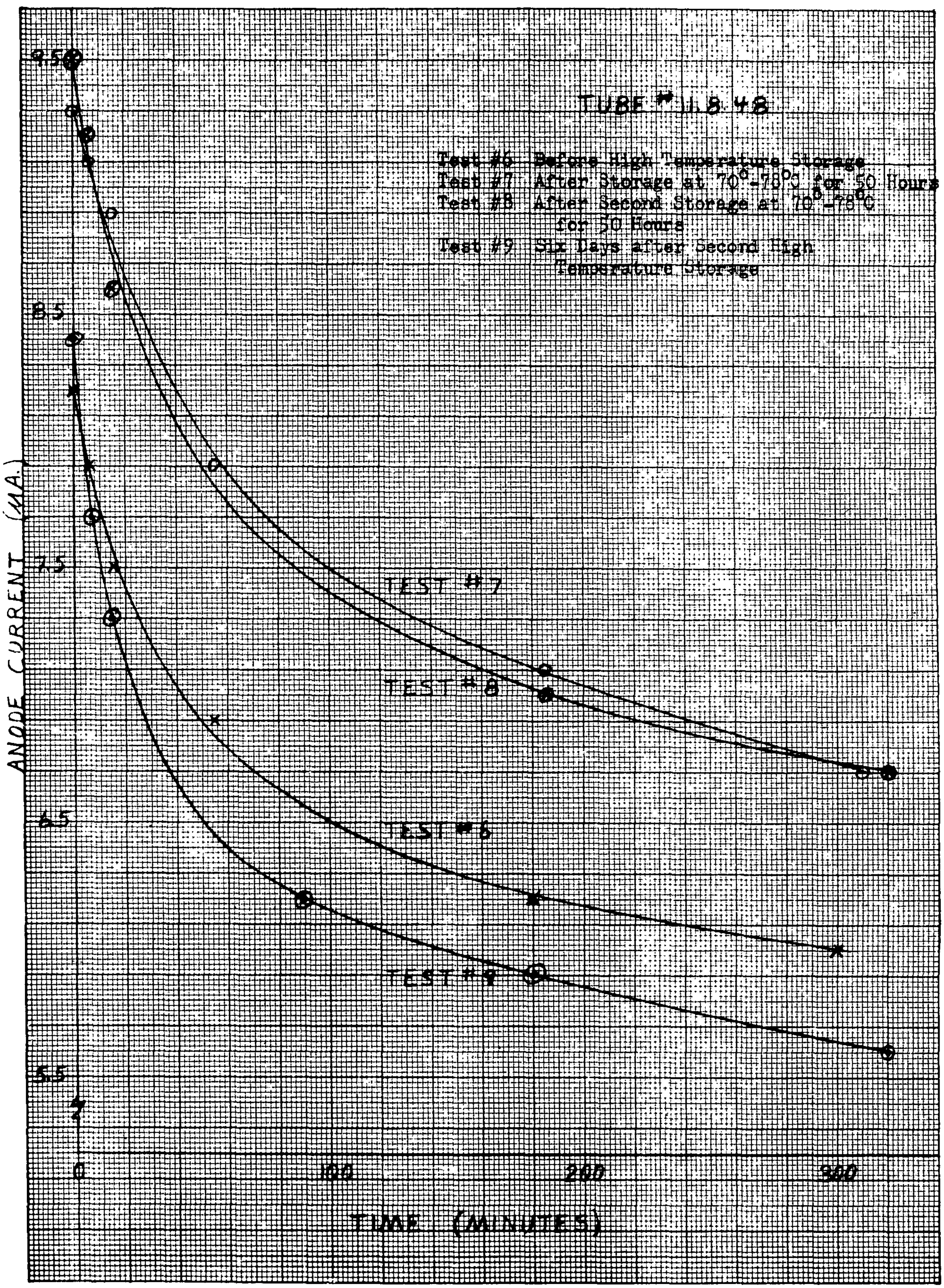


Fig. 48 - Effect of High Temperature Storage on 7029 Photomultipliers

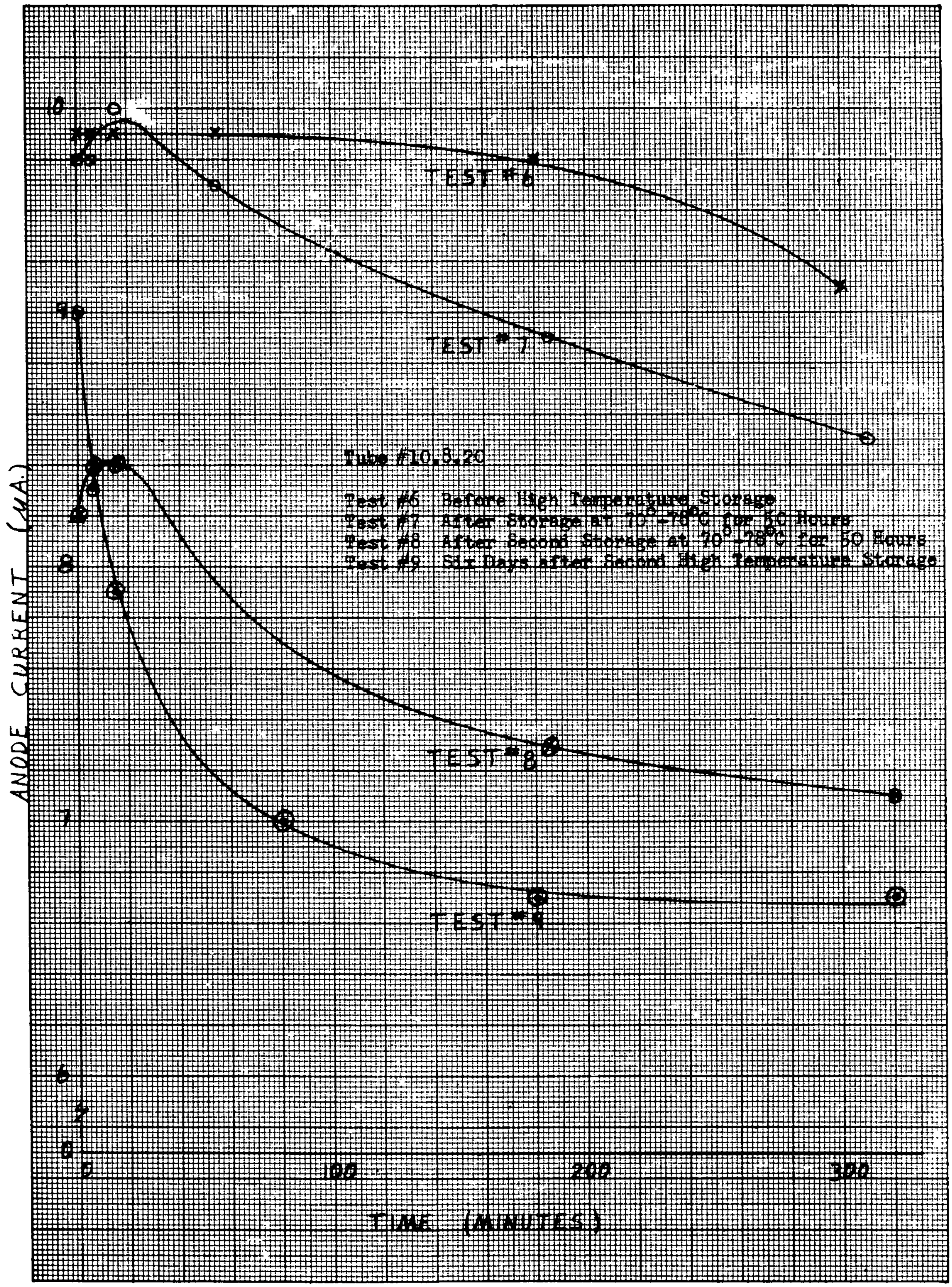


Fig. 19 - Effect of High Temperature Storage on 7029 Photomultipliers

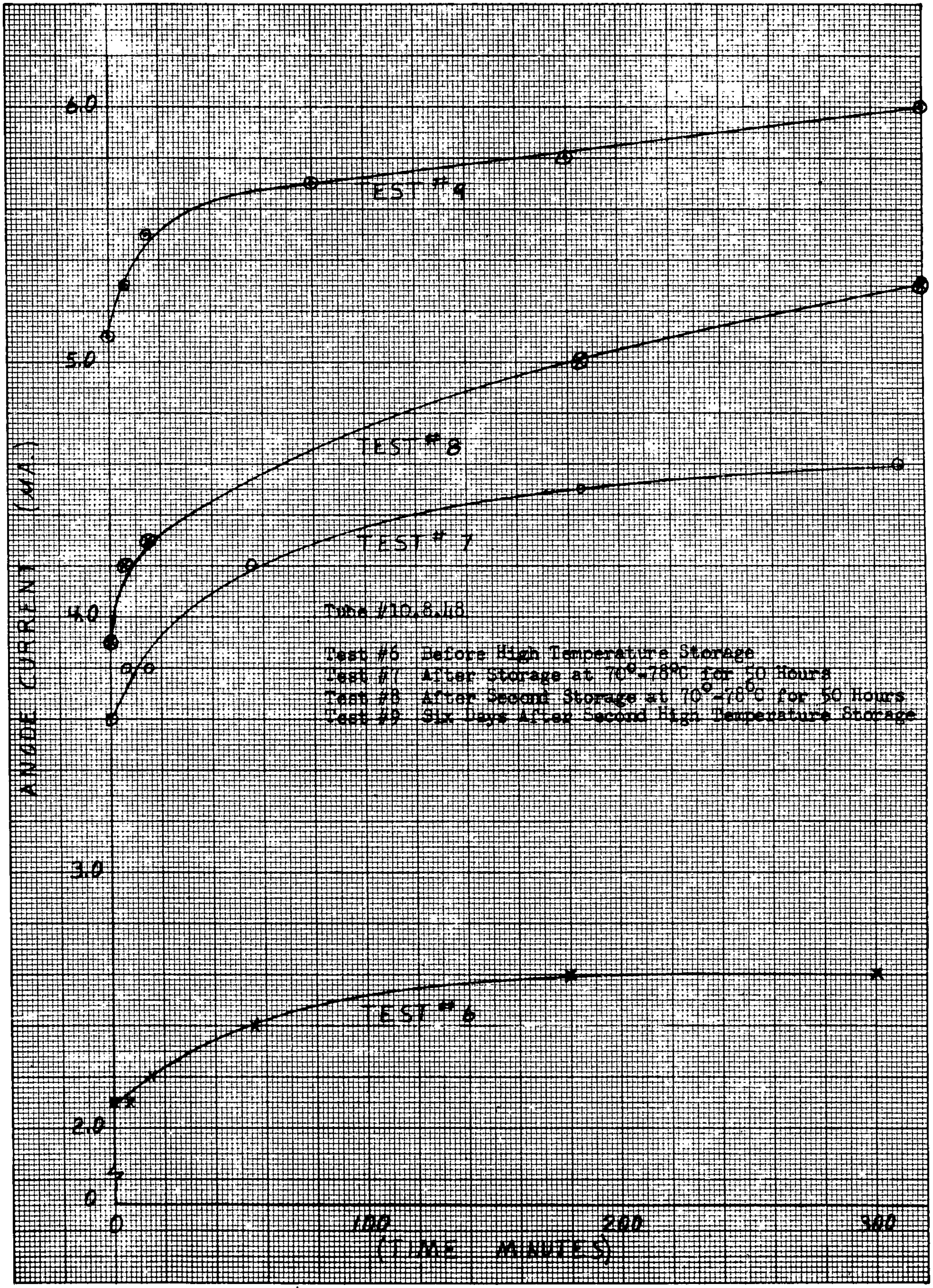


Fig. 50 - Effect of High Temperature Storage on 7029 Photomultiplier

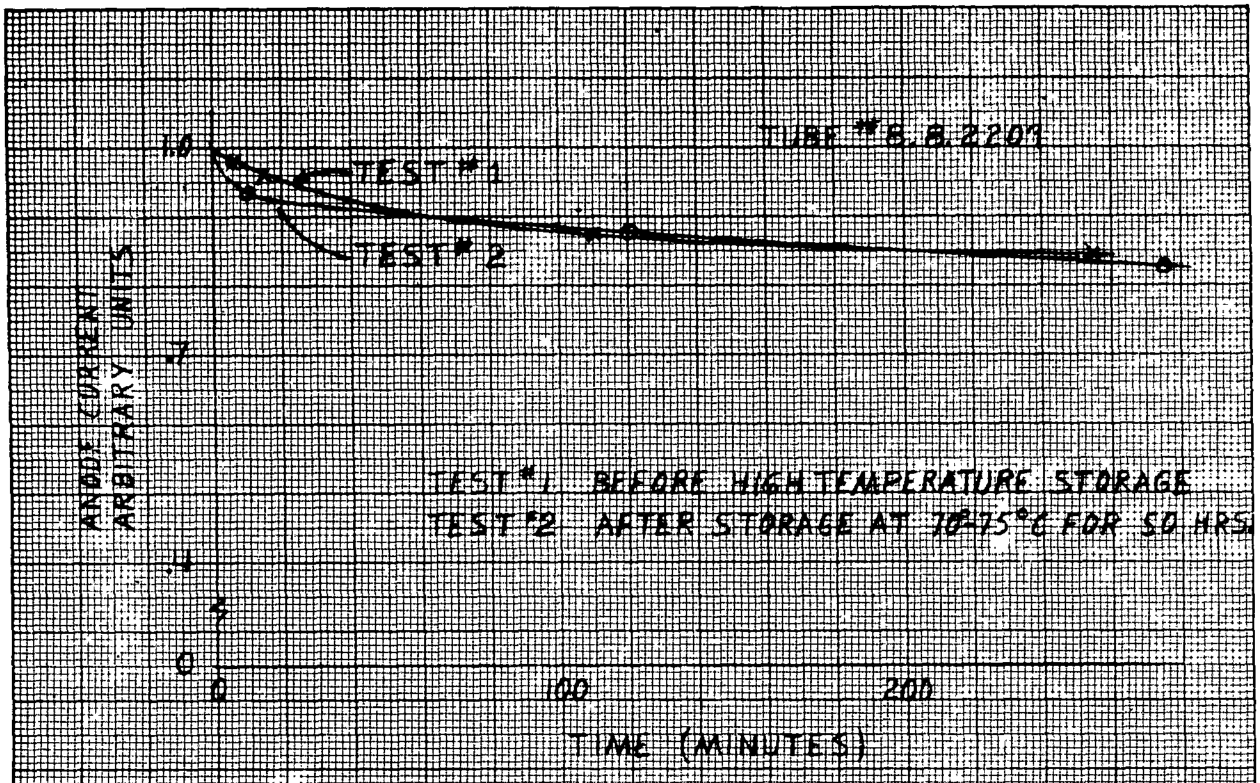


Fig. 51 - Effect of High Temperature Storage on 7029 Photomultiplier

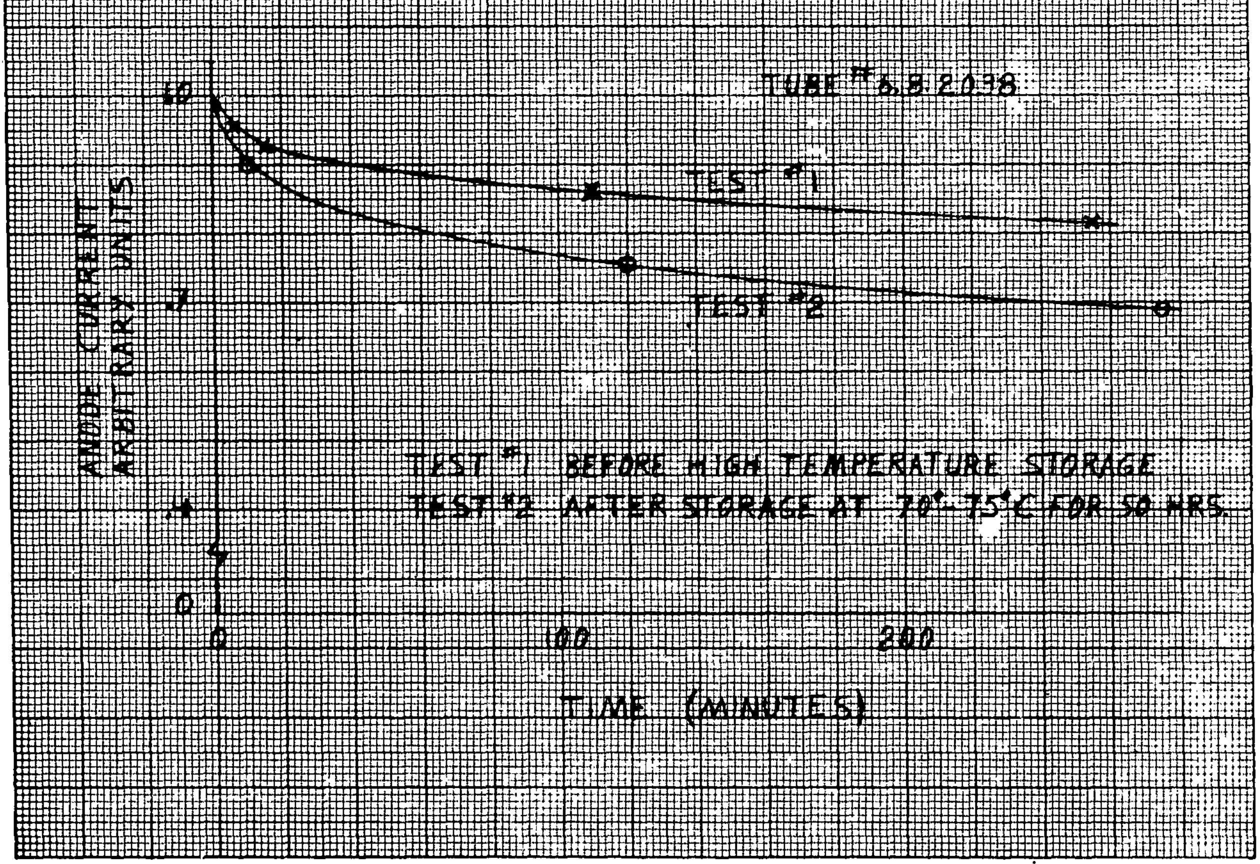


Fig. 52 - Effect of High Temperature Storage on 7029 Photomultiplier

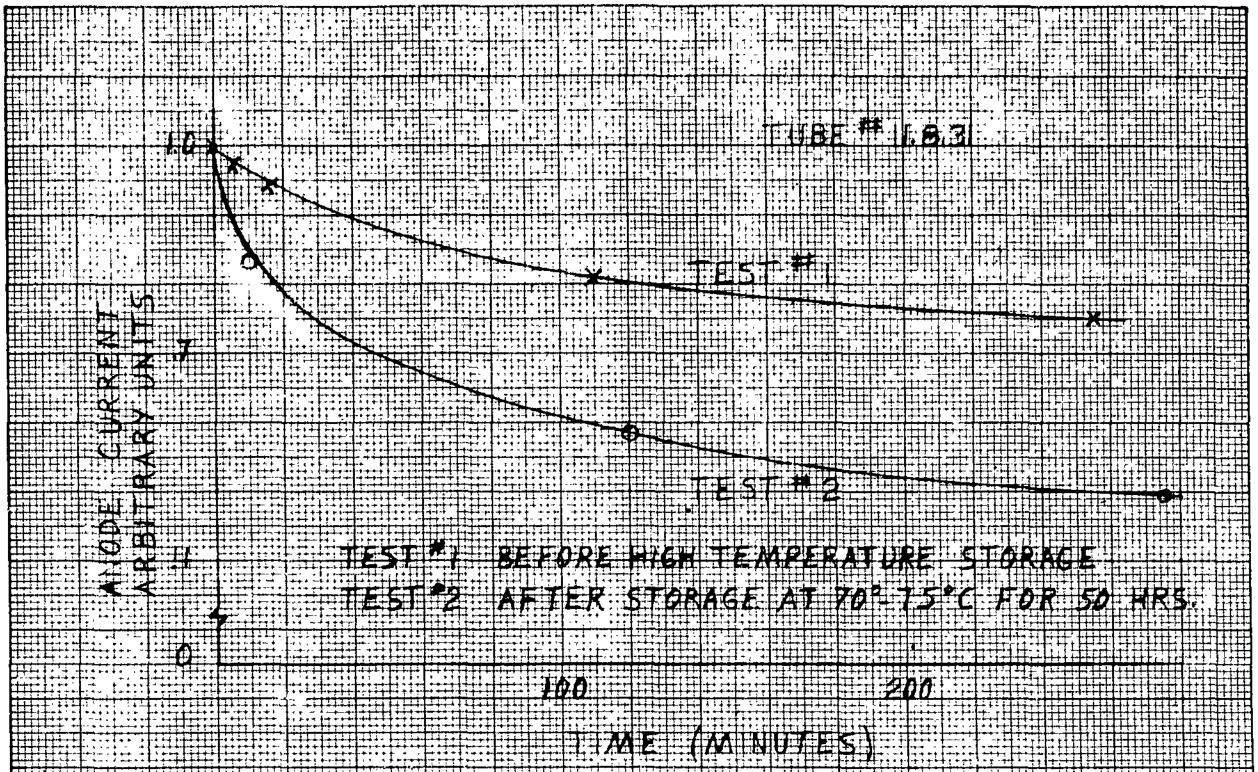


Fig. 53 - Effect of High Temperature Storage on a 7029 Photomultiplier

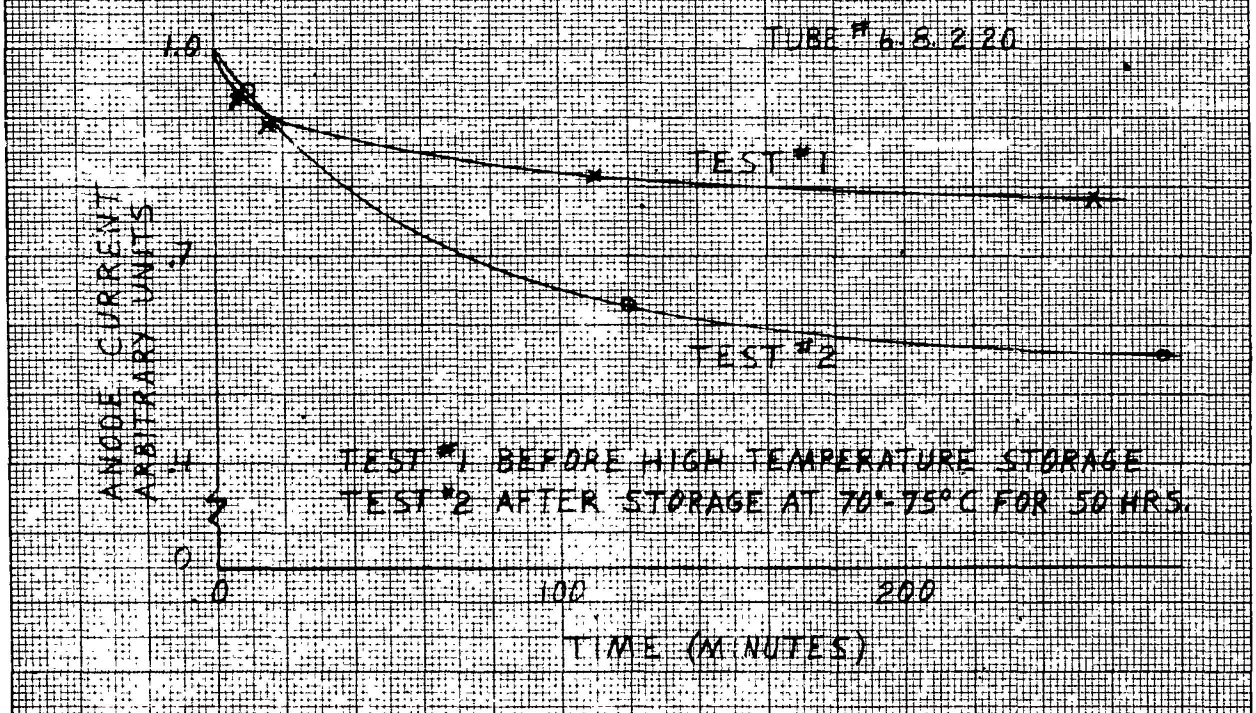


Fig. 54 - Effect of High Temperature Storage on a 7029 Photomultiplier

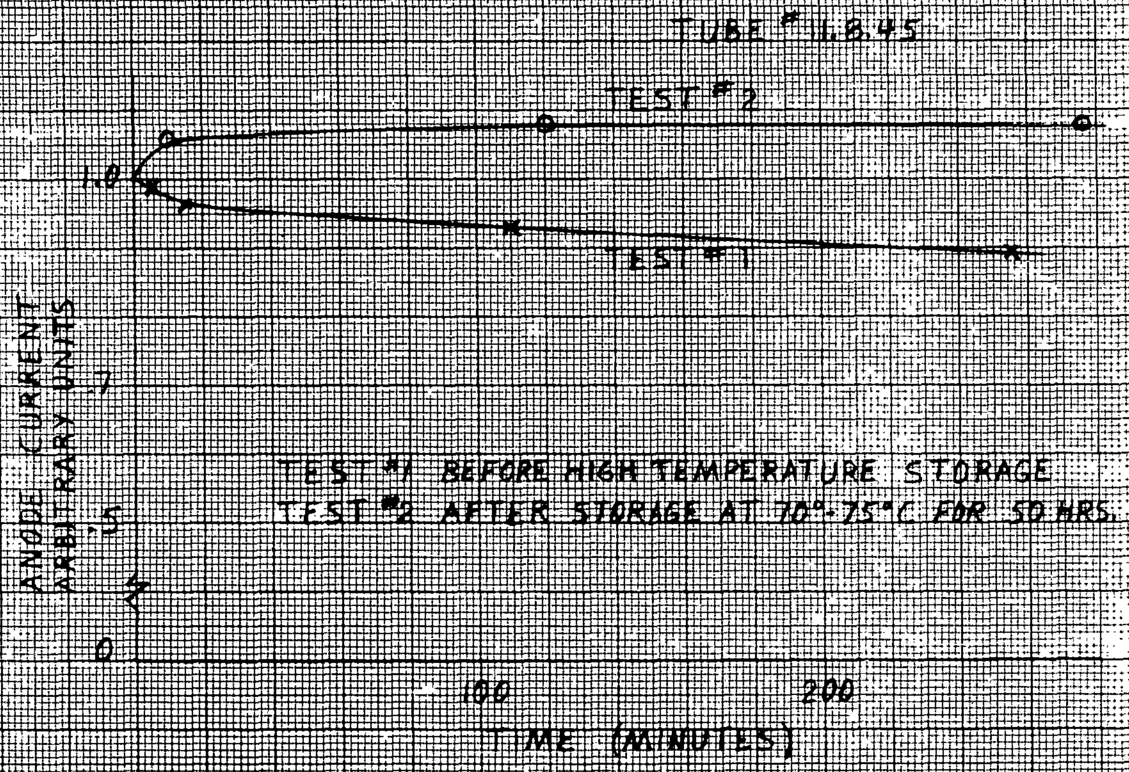


Fig. 55 - Effect of High Temperature Storage on a 7029 Photomultiplier

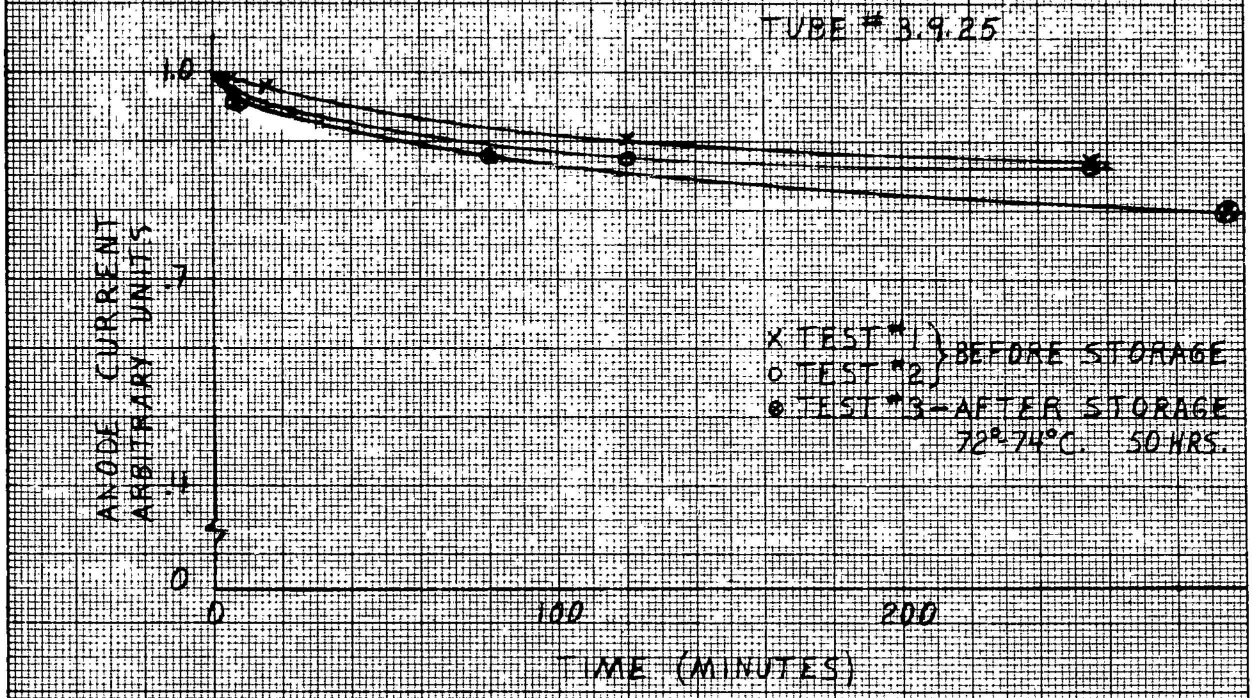


Fig. 56 - Effect of High Temperature Storage on a 7029 Photomultiplier

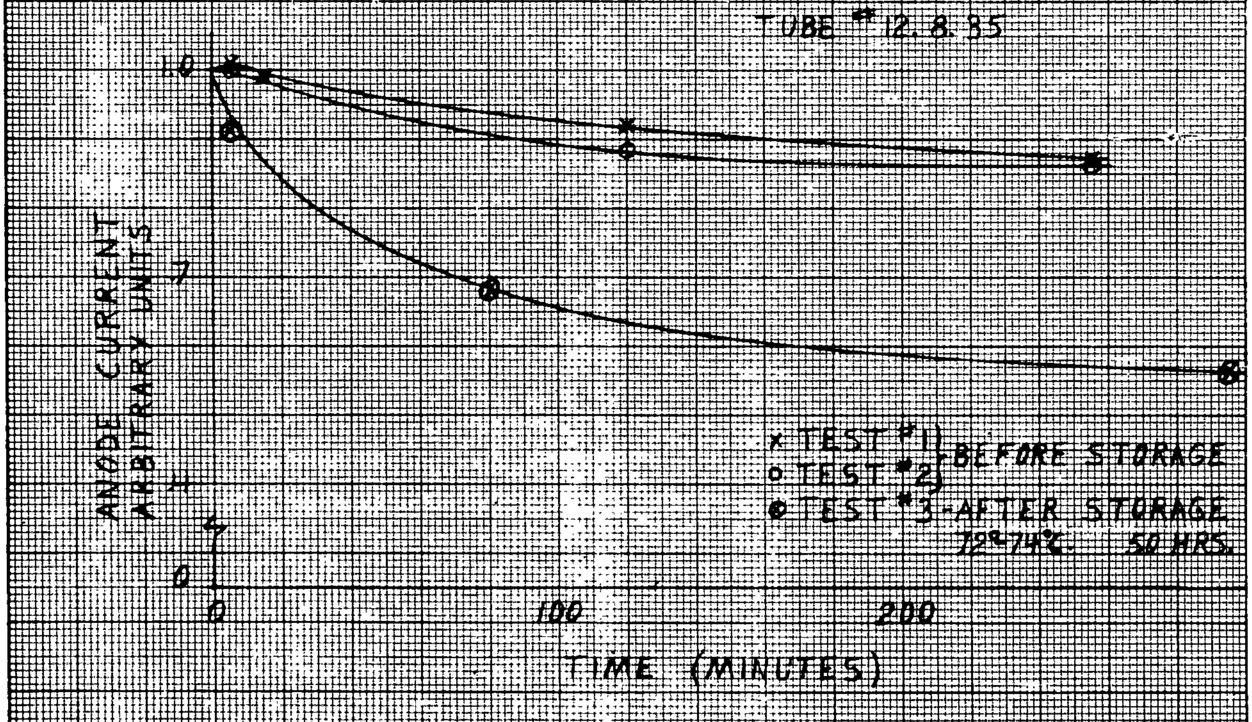


Fig. 57 - Effect of High Temperature Storage on a 7029 Photomultiplier

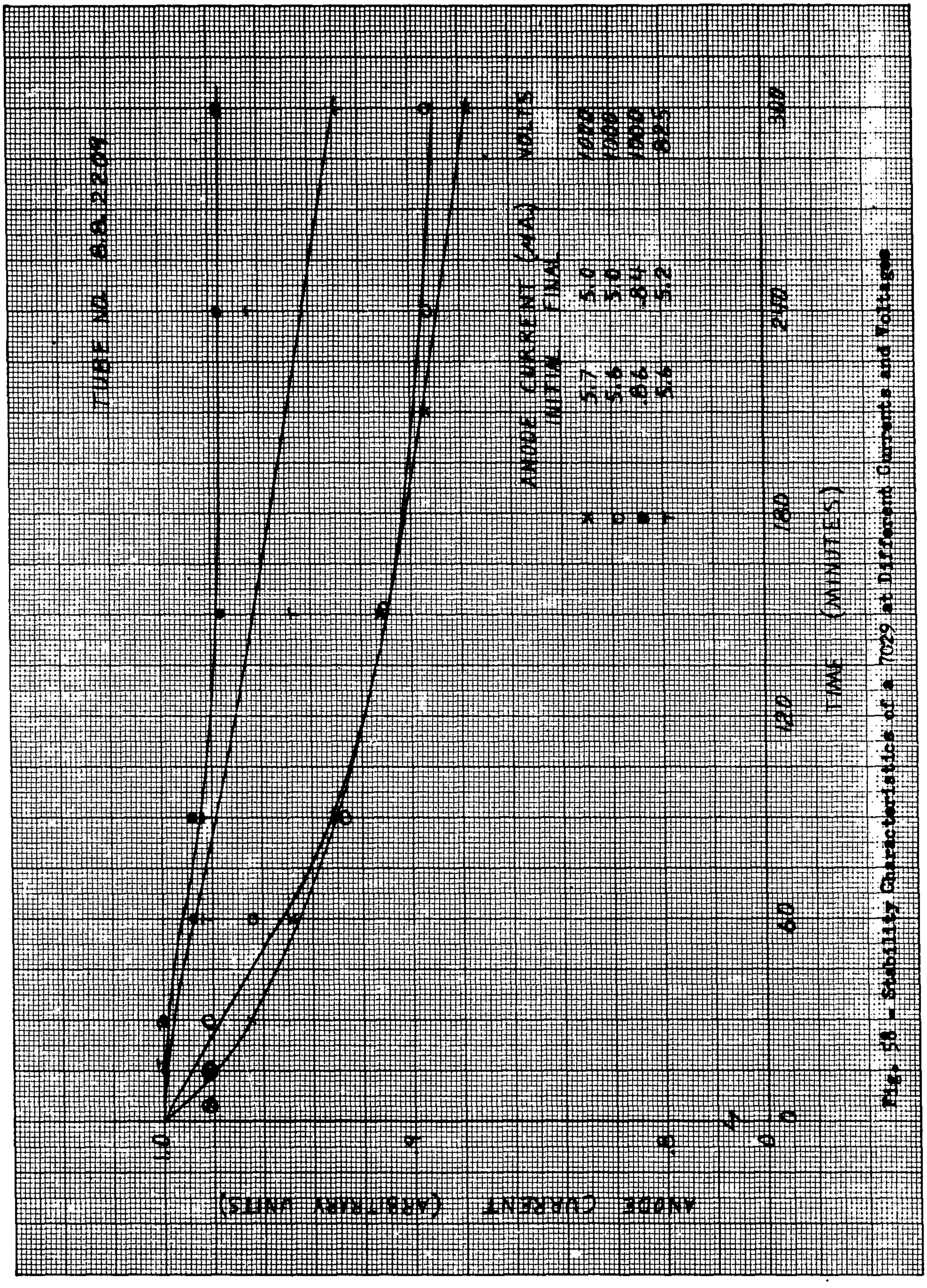


Fig. 58 - Stability Characteristics of a 7029 at Different Currents and Voltages

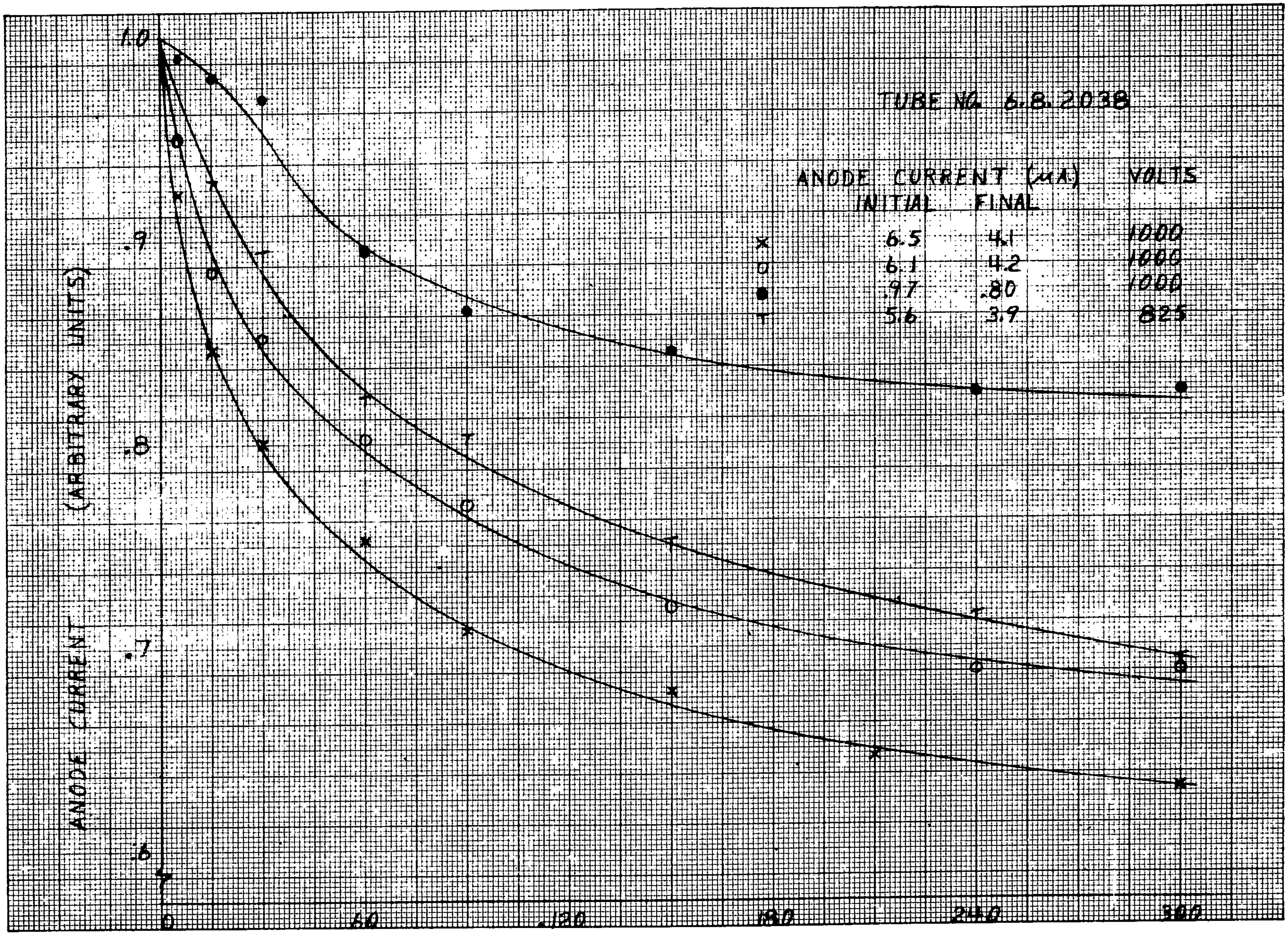


Fig. 59 - Stability Characteristics of a 7029 at Different Currents and Voltages

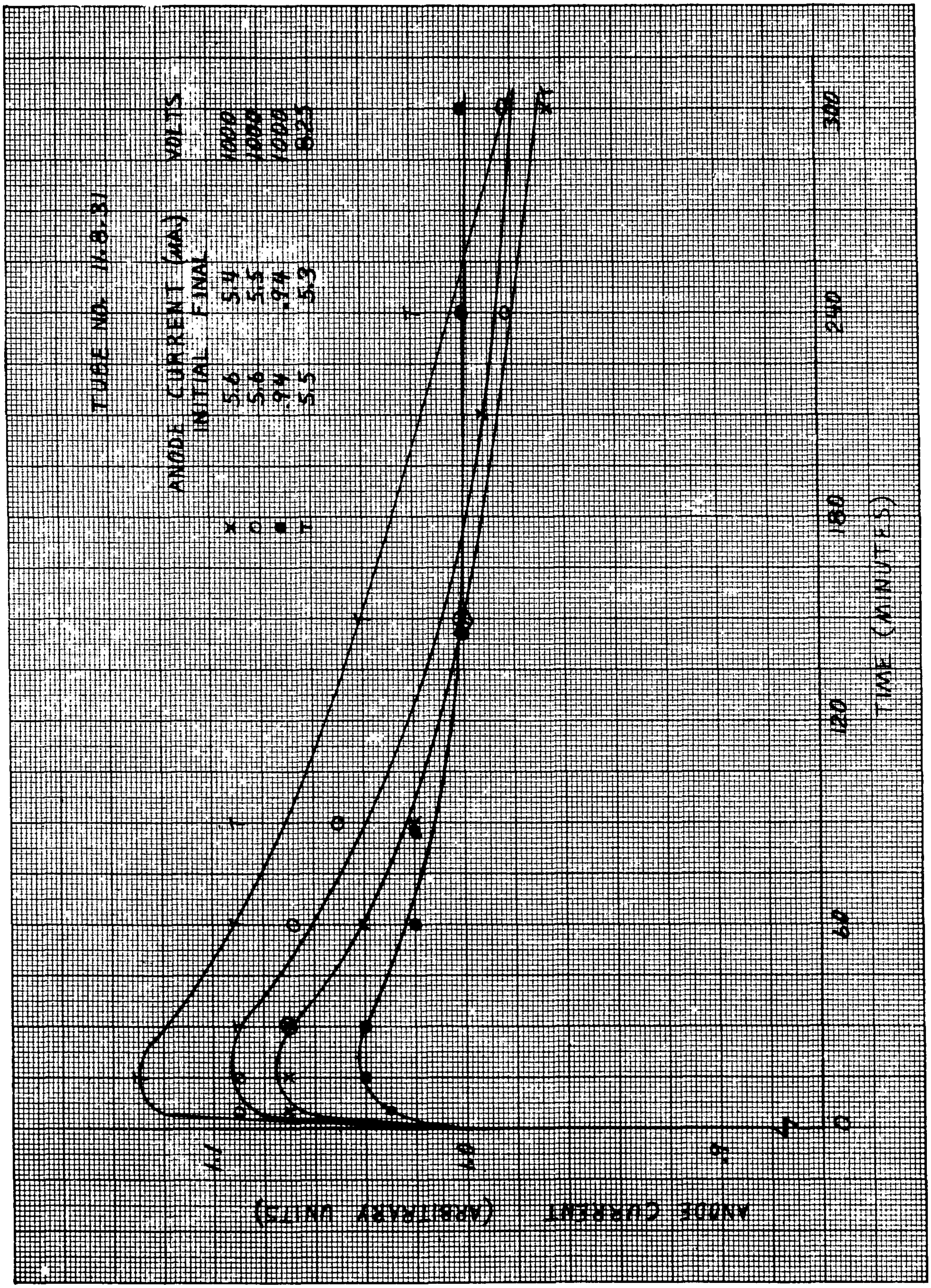


Fig. 60 - Stability Characteristics of a 7029 at Different Currents and Voltages

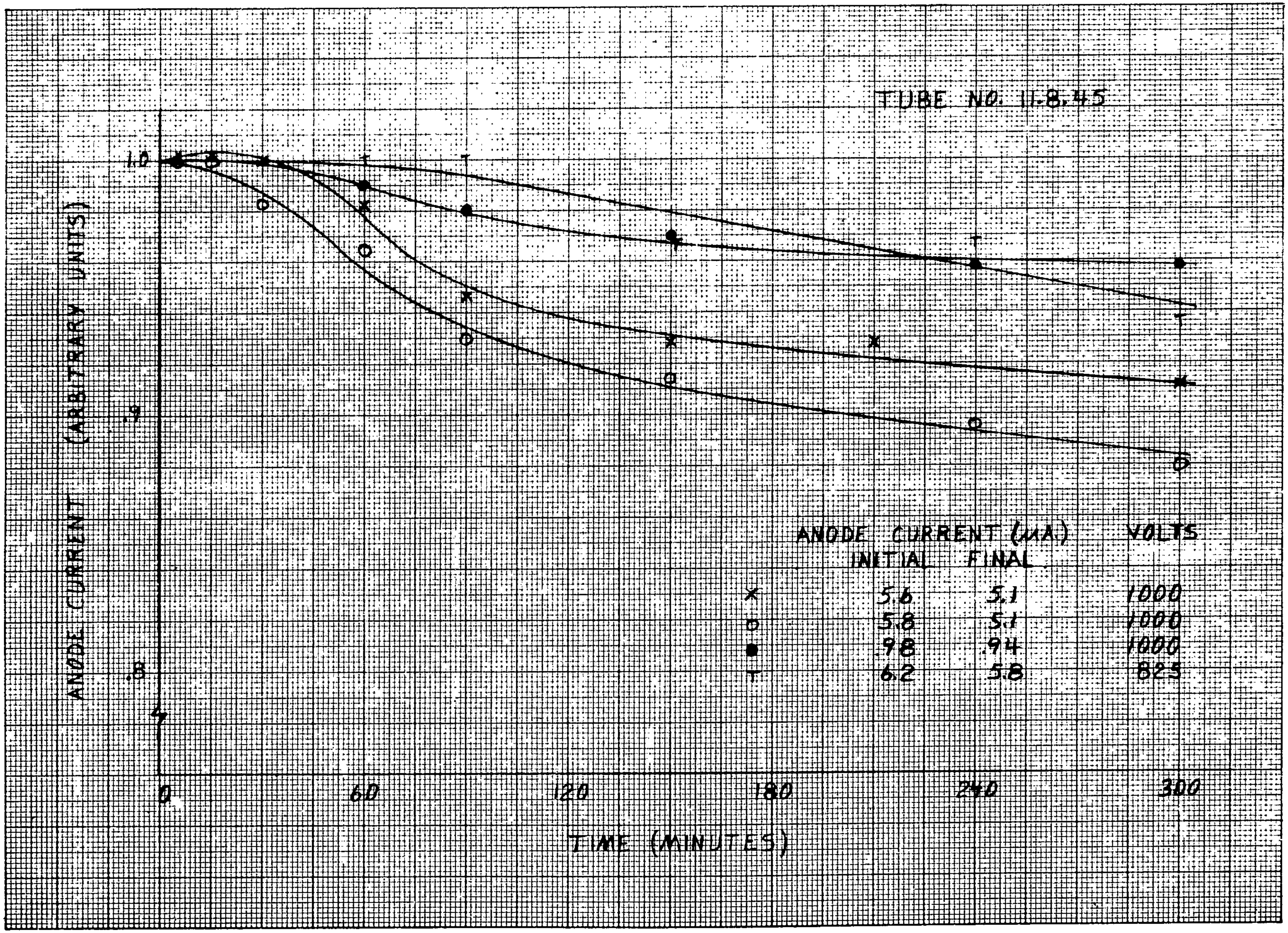


Fig. 61 - Stability Characteristics of a 7029 at Different Currents and Voltages

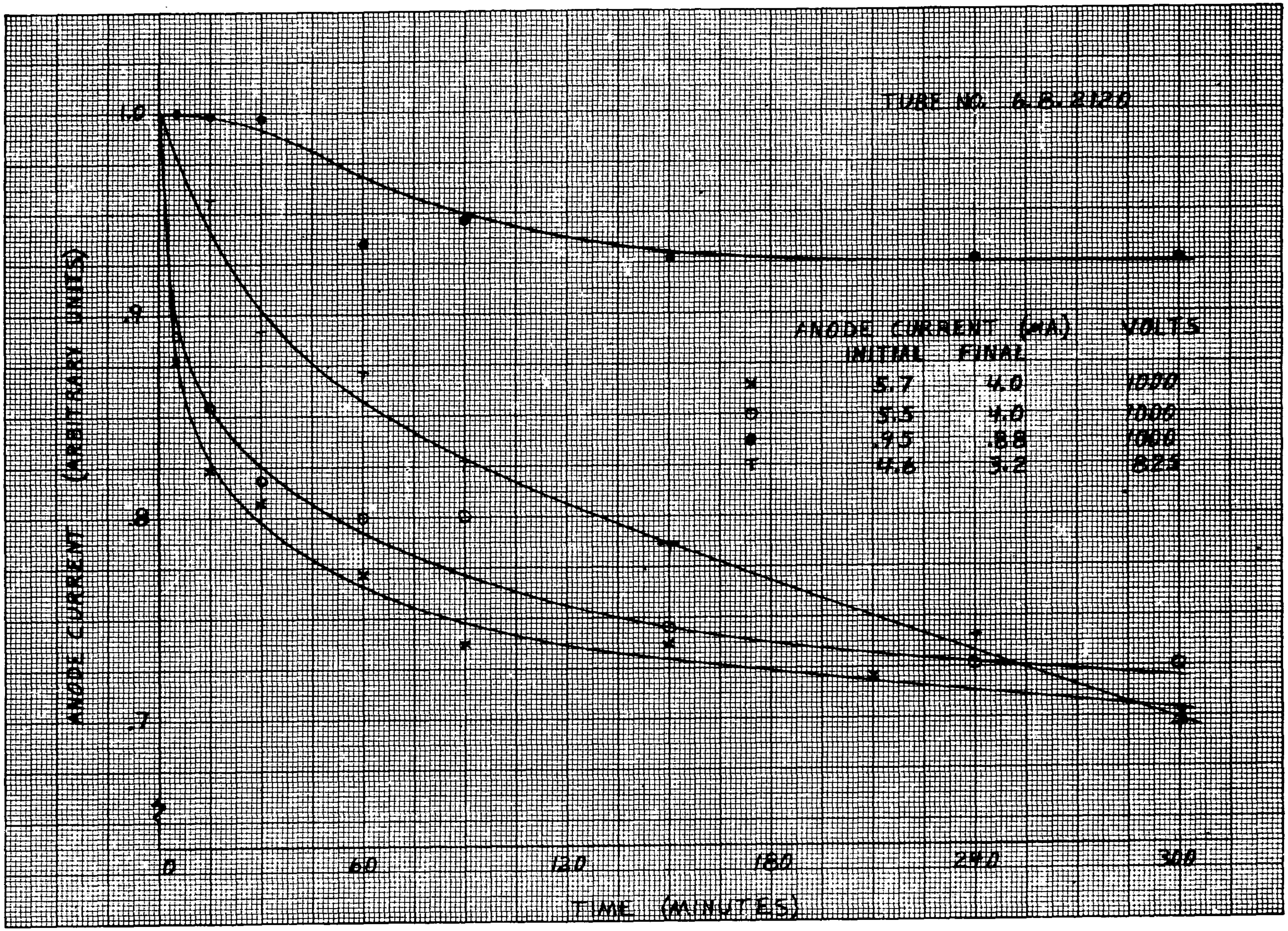


Fig. 62 - Stability Characteristics of a 7029 at Different Currents and Voltages

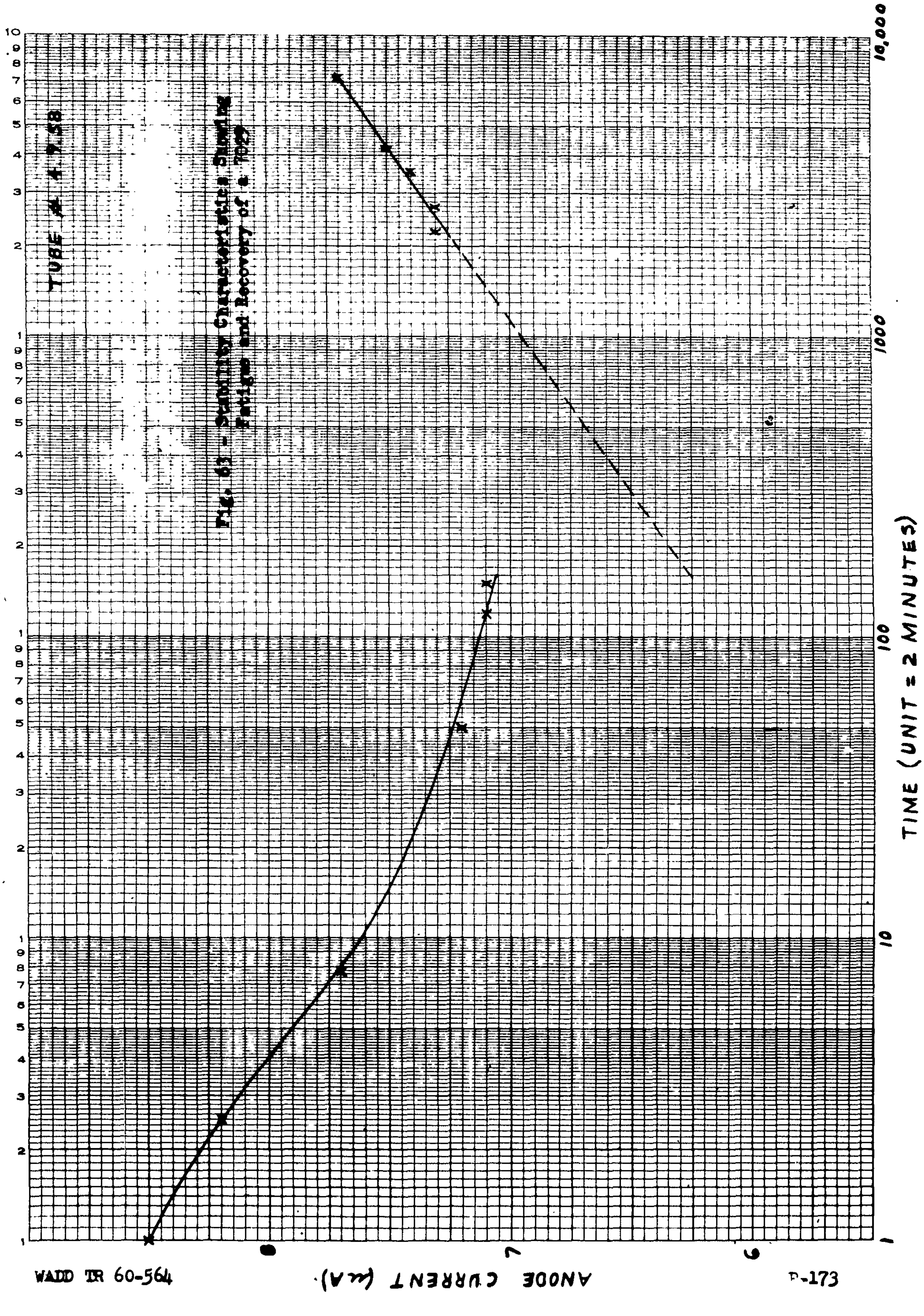
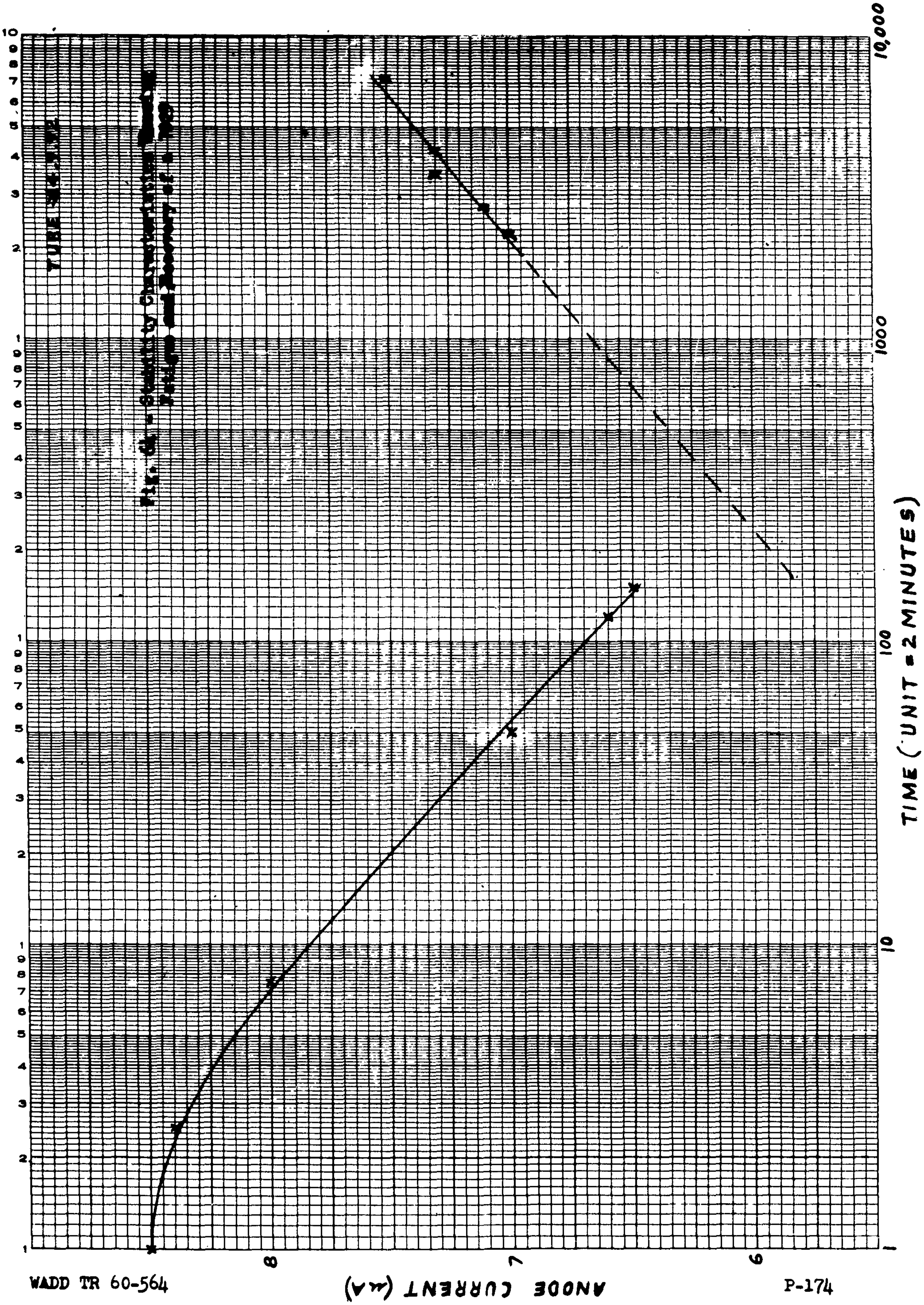


Fig. 63 - Stability Characteristics Showing Fatigue and Recovery of a 7029



TIME (UNIT = 2 MINUTES)
1
10
100
1000
10,000
ANODE CURRENT (μA)
8
7
6

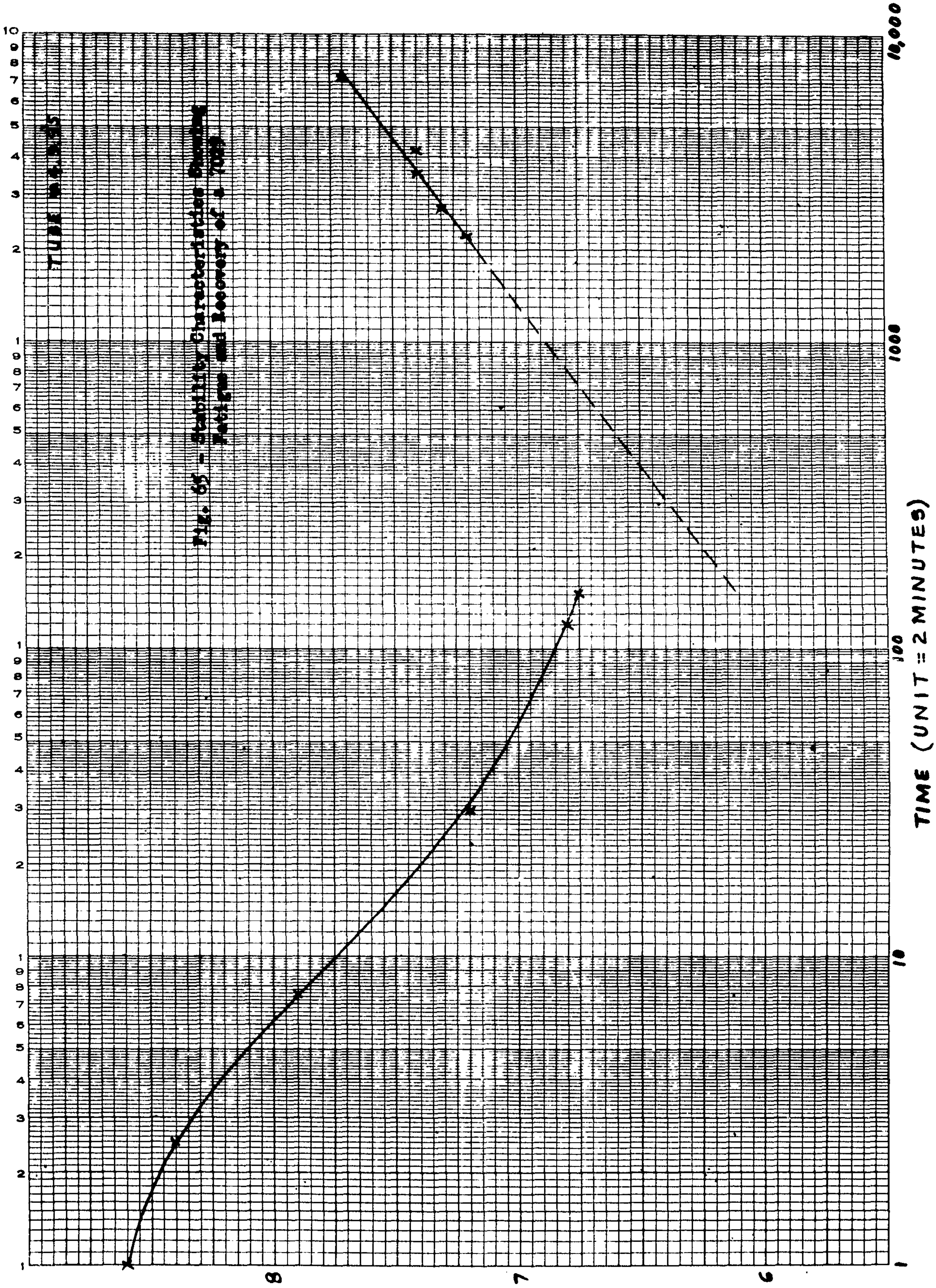


Fig. 65 - Stability Characteristics Showing Fatigue and Recovery of a Tube

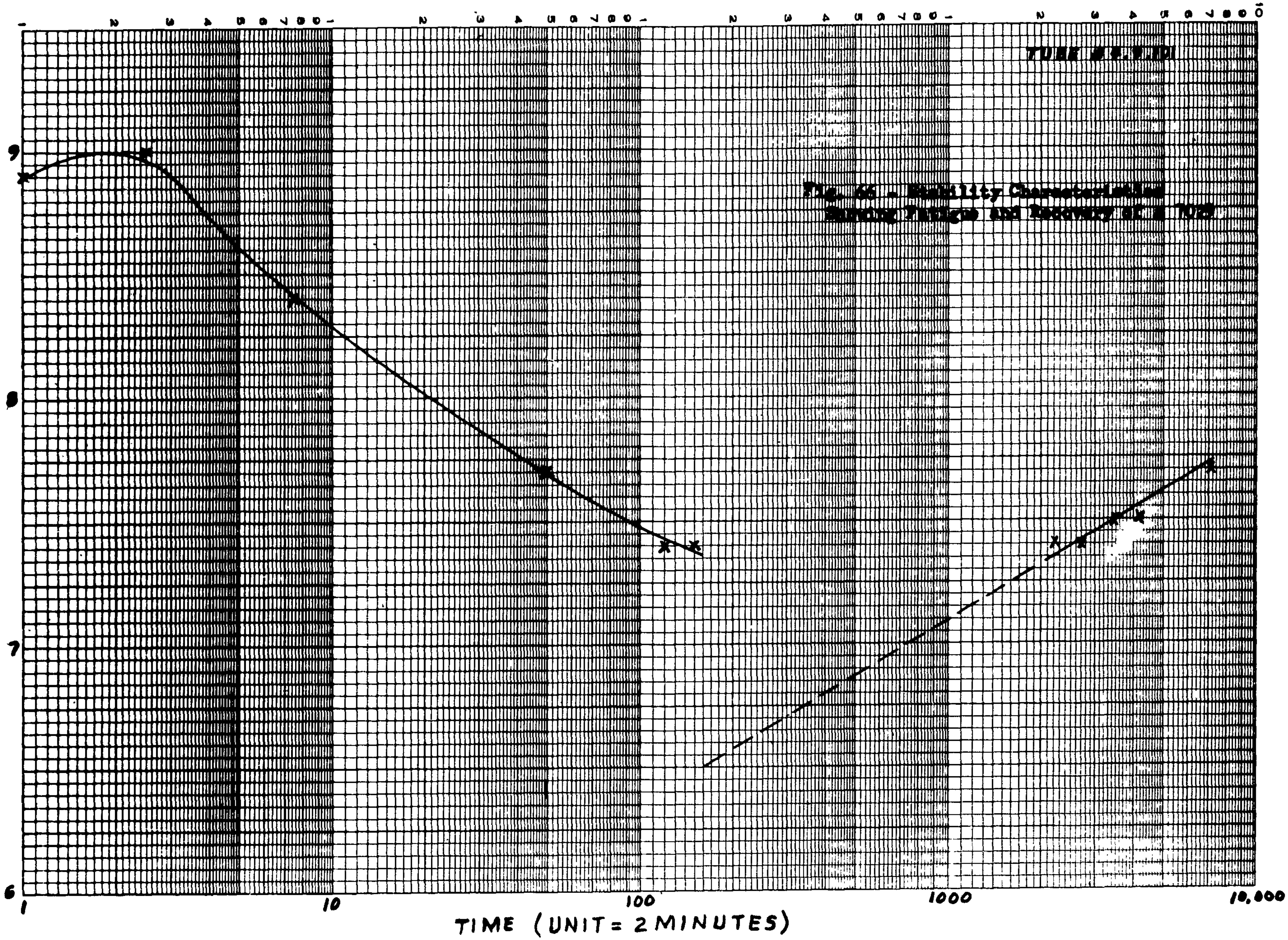


Fig. 66 - Stability Characteristics During Fatigue and Recovery of K 7029

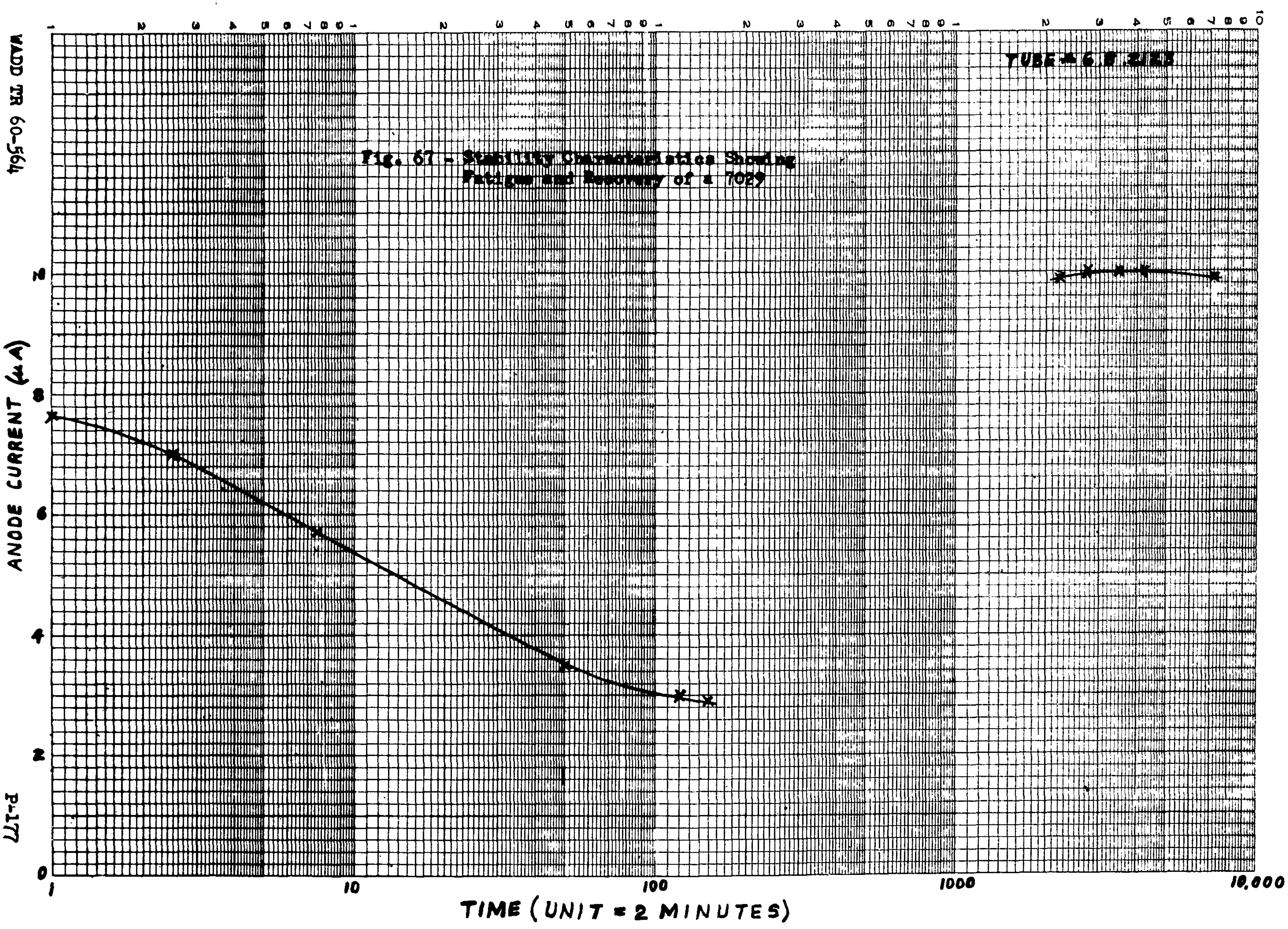


Fig. 67 - Stability Characteristics Showing Fatigue and Recovery of a 7029

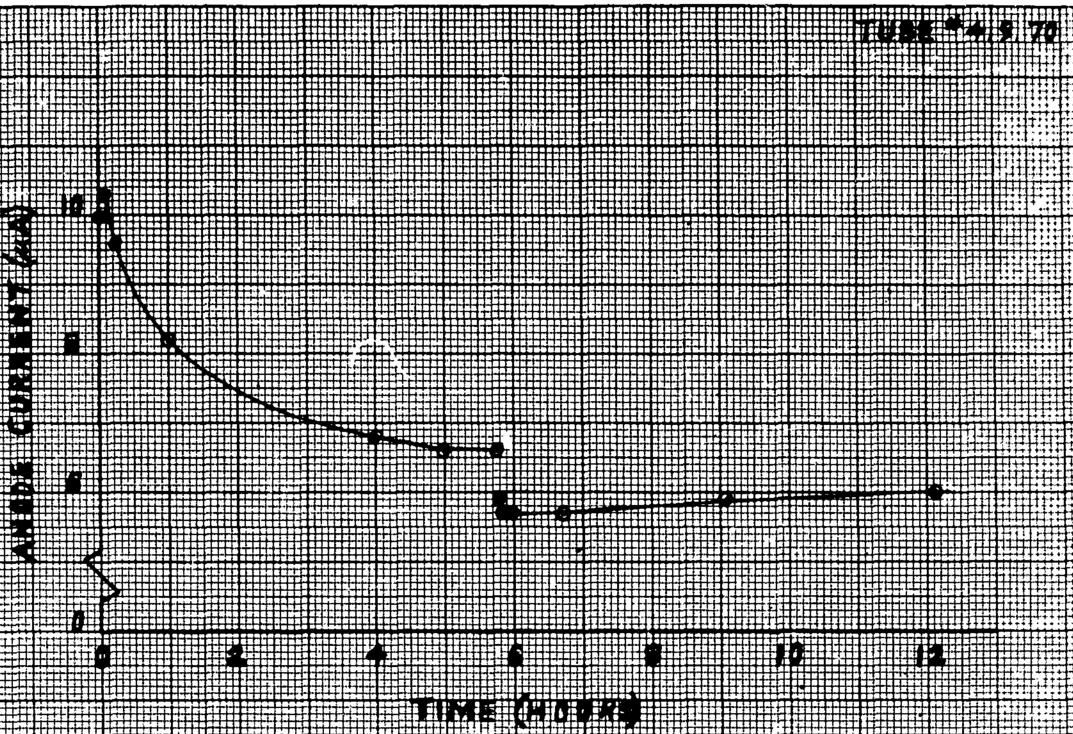


Fig. 68 – Stability Characteristics Showing Fatigue and Recovery of a 7029

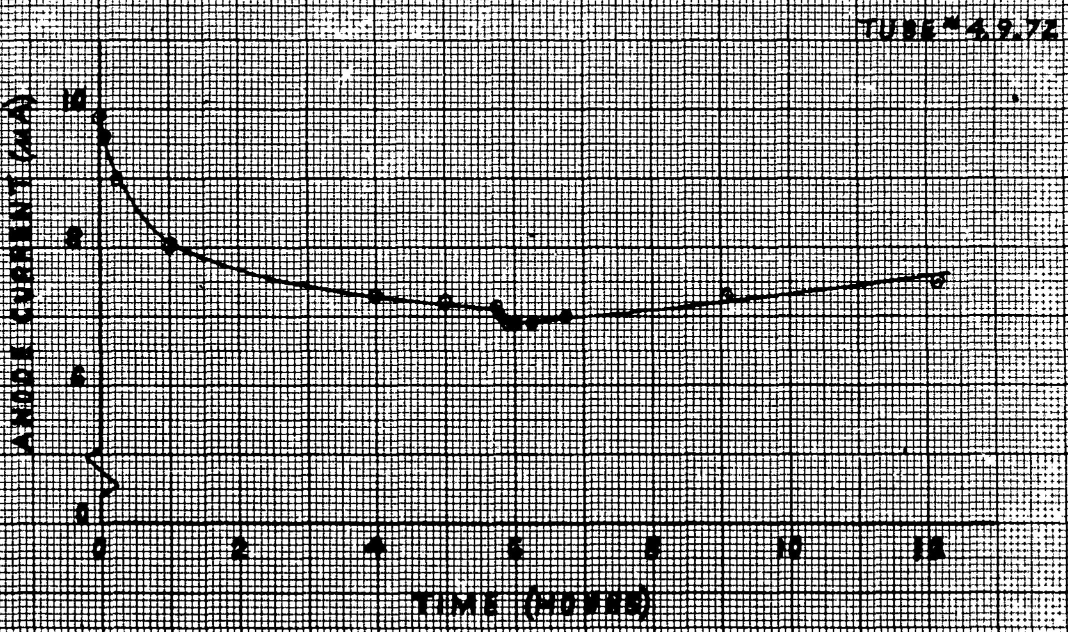


Fig. 69 – Stability Characteristics Showing Fatigue and Recovery of a 7029

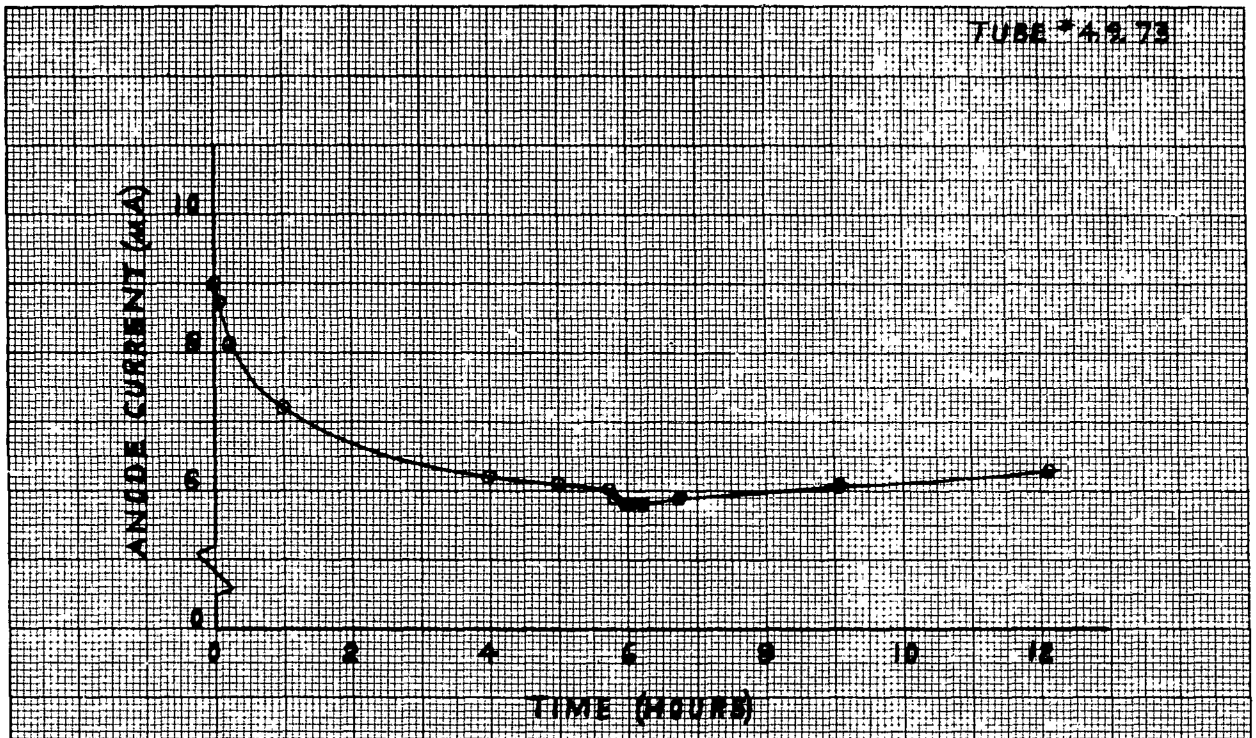


Fig. 70 - Stability Characteristics Showing Fatigue and Recovery of a 7029

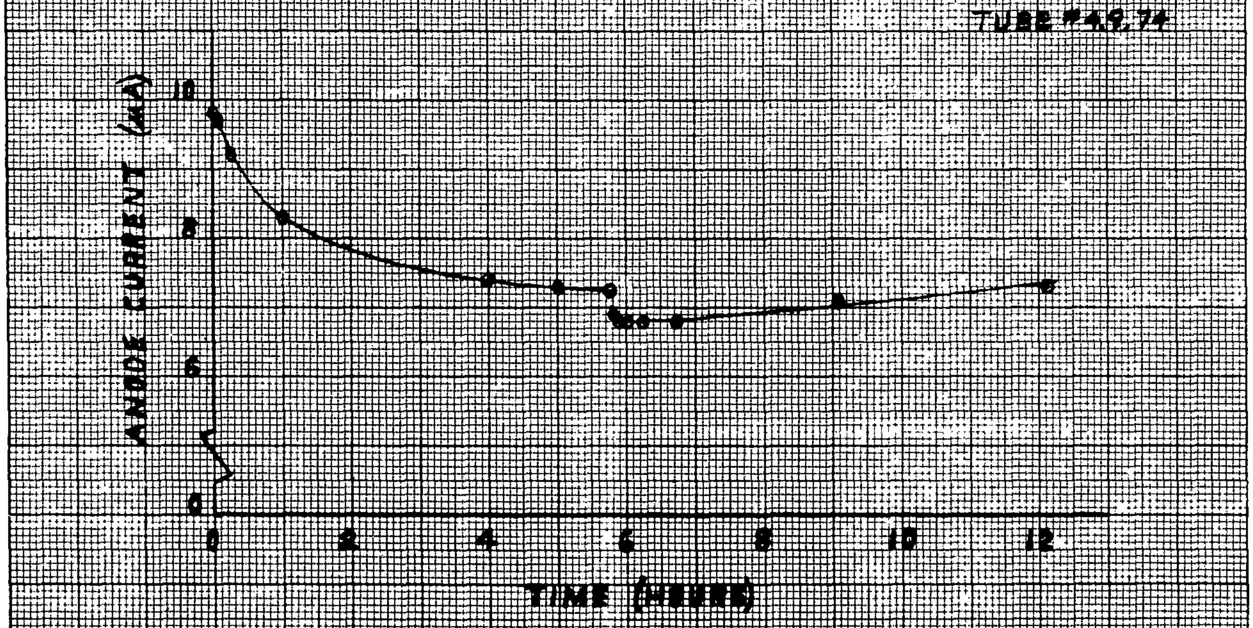


Fig. 71 - Stability Characteristics Showing Fatigue and Recovery of a 7029

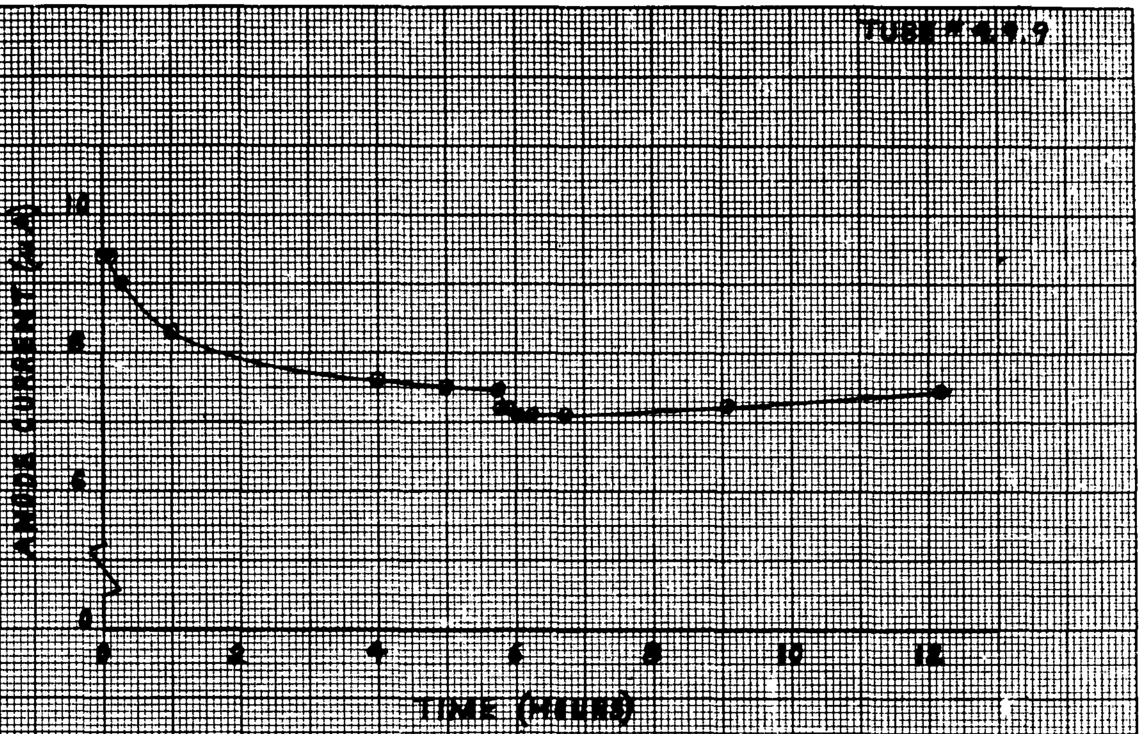


Fig. 72 - Stability Characteristics Showing Fatigue and Recovery of a 7029

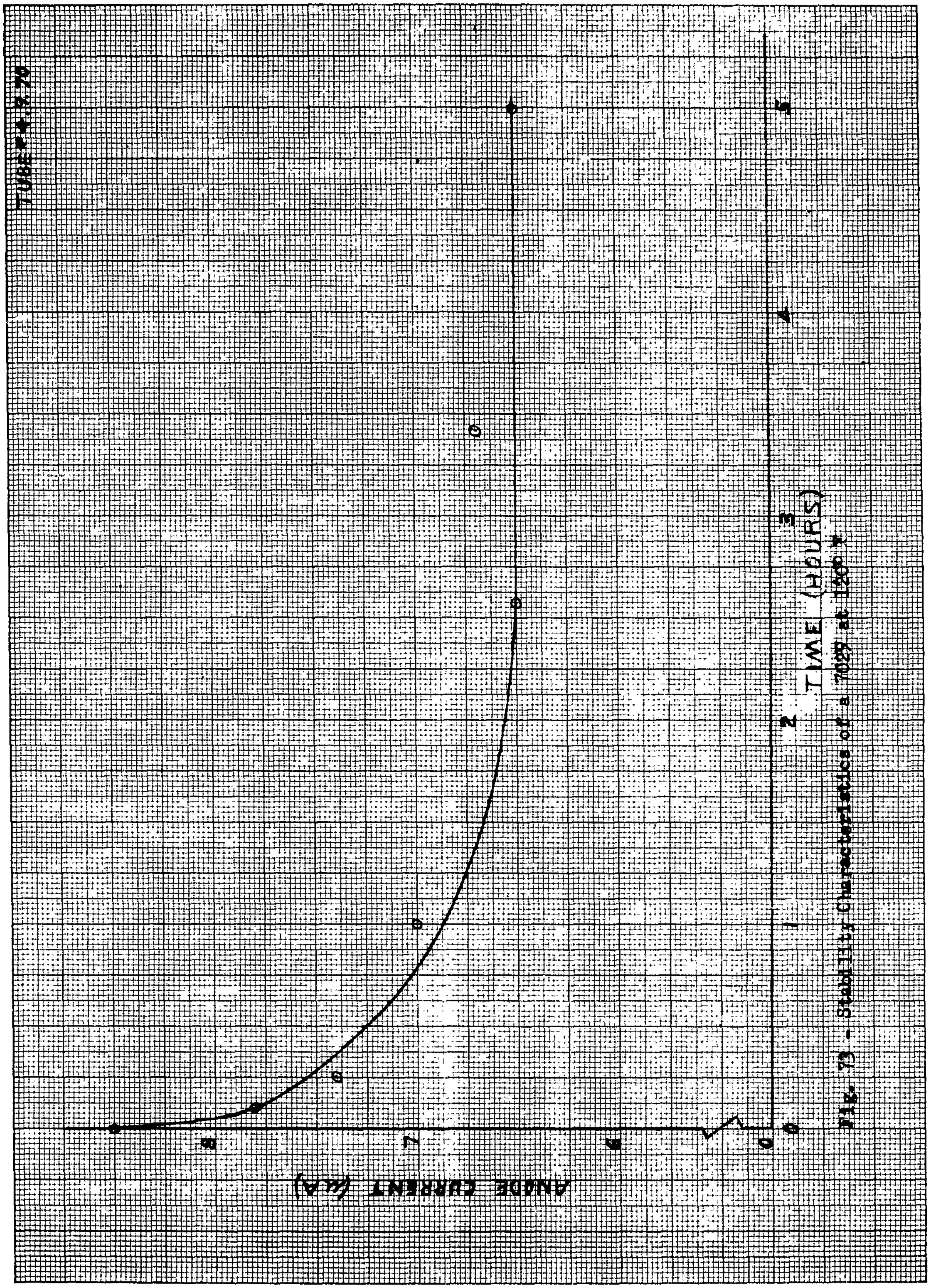


Fig. 73 - Stability Characteristics of a 7029 at 1200 V

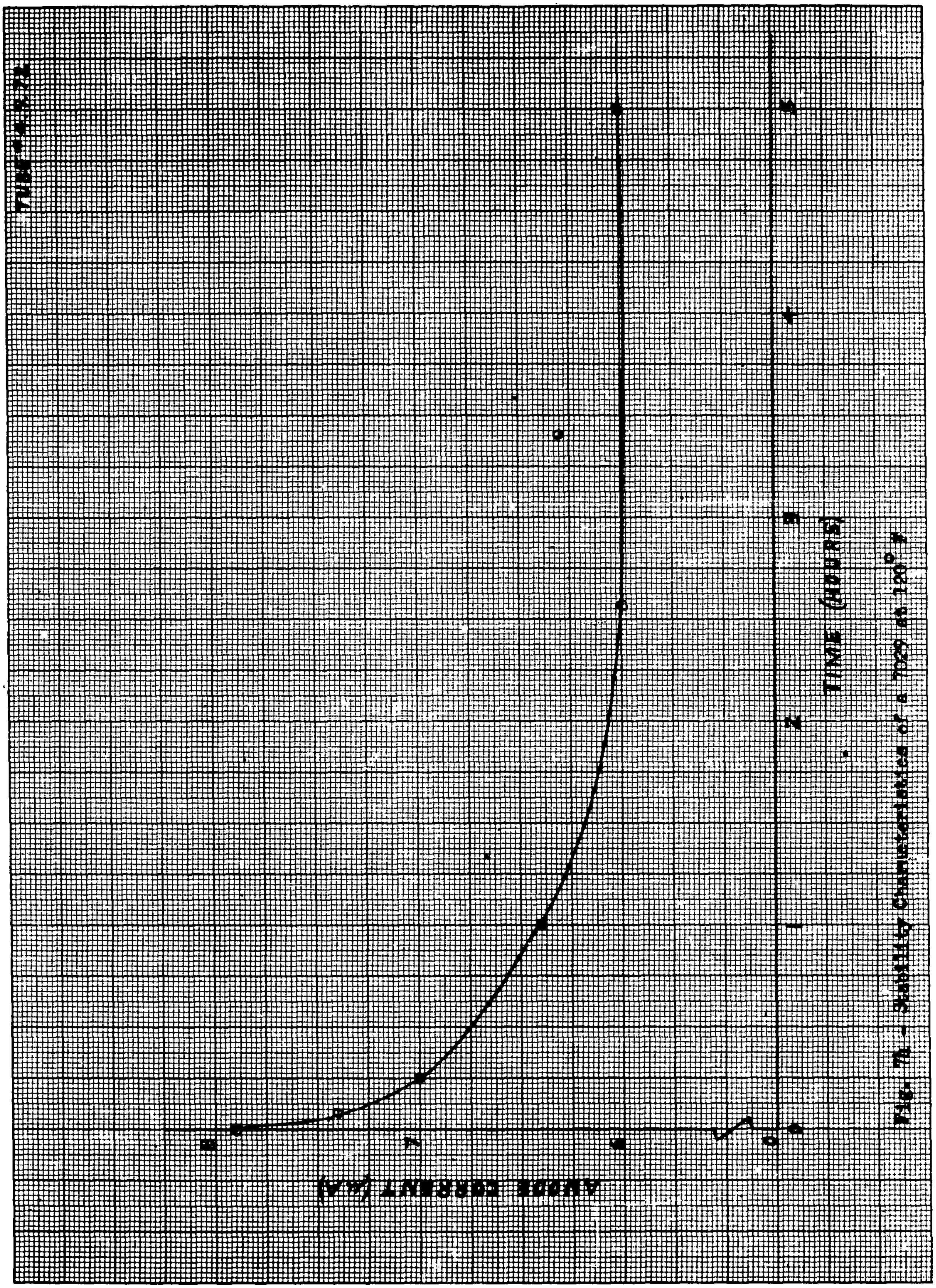


Fig. 74 - Stability Characteristics of a 7029 at 120° F

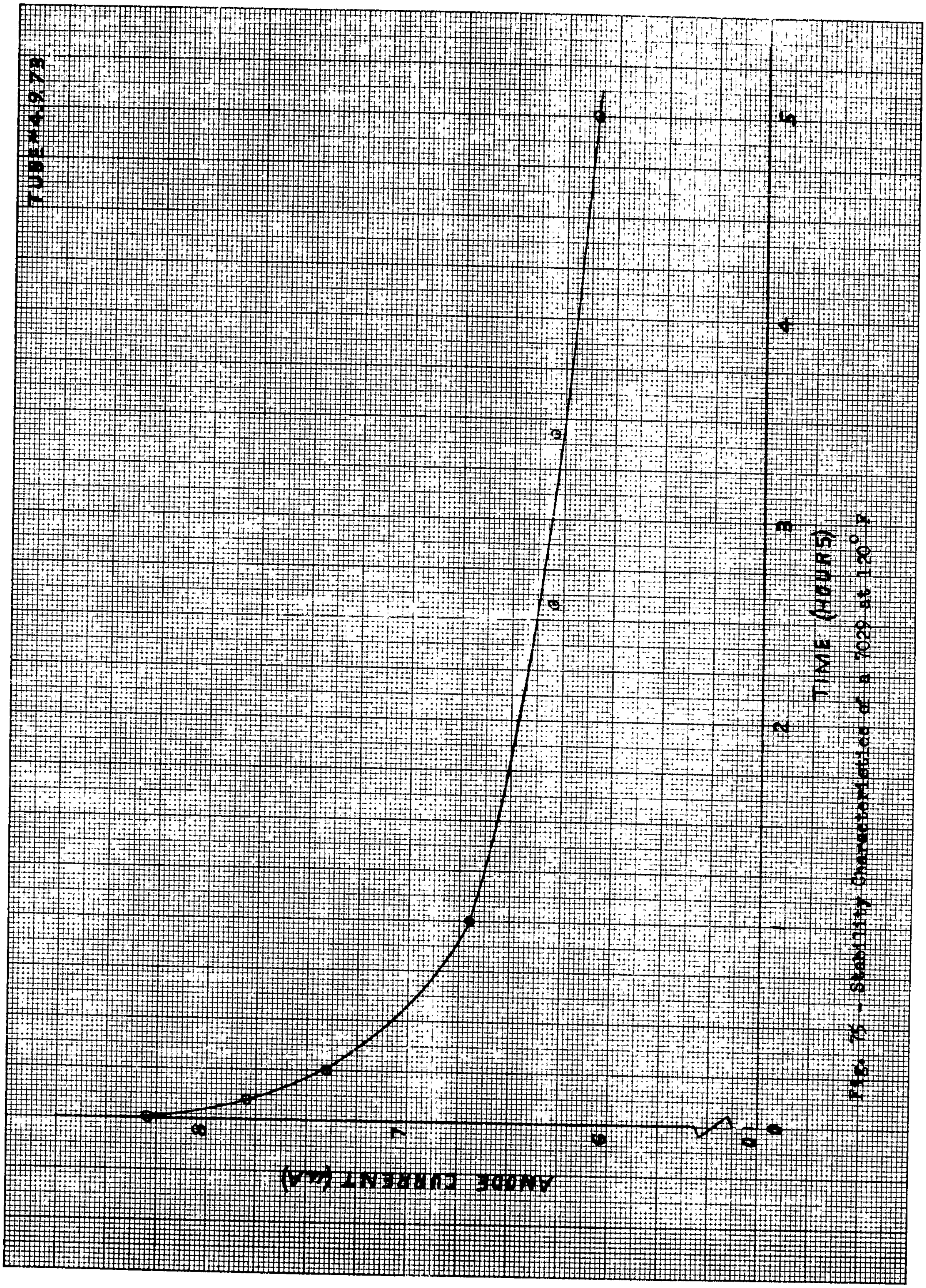


Fig. 75 - Stability Characteristics of a 7029 at 120° F

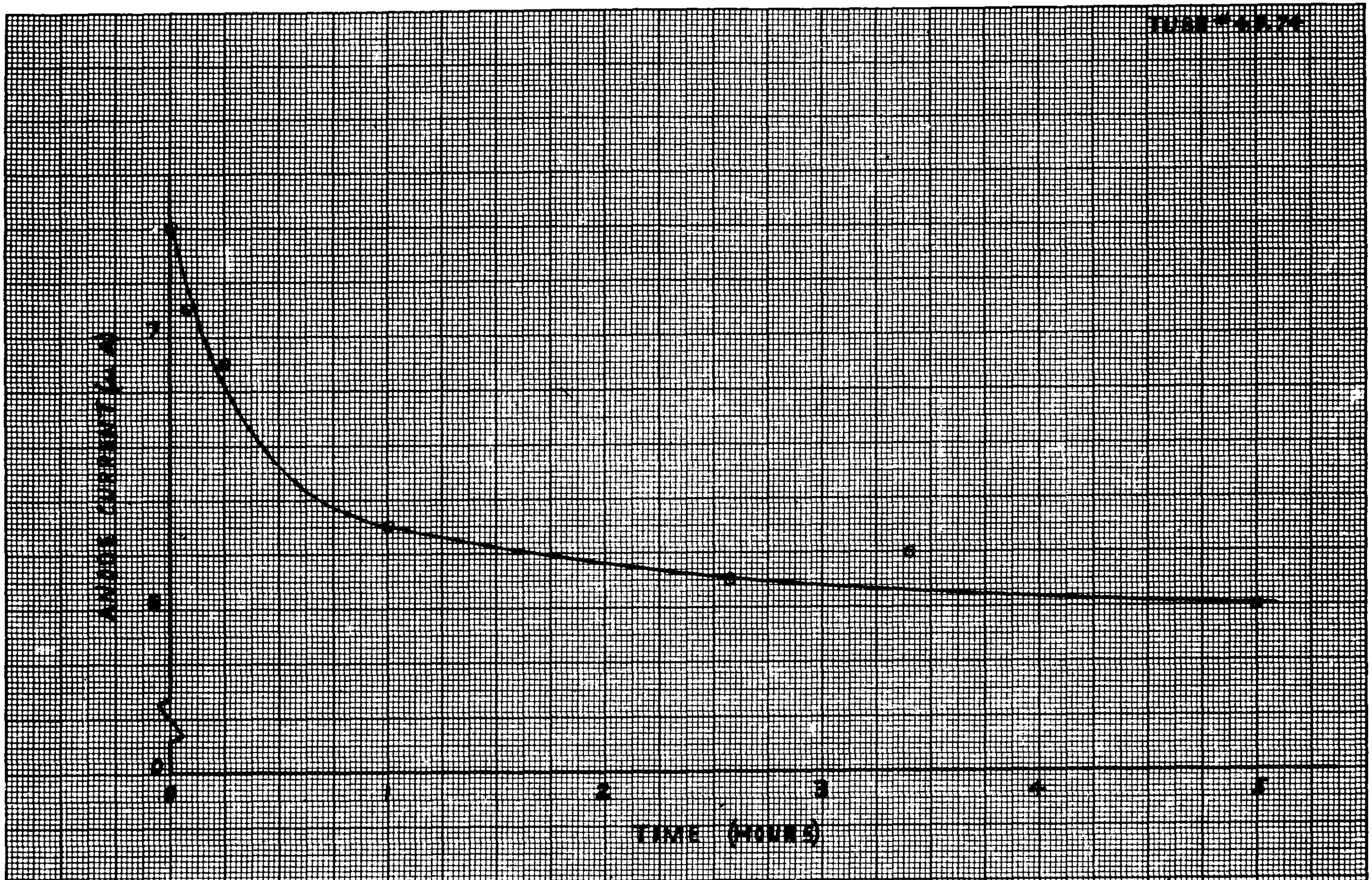


Fig. 75 - Stability Characteristics of a 7029 at 120° F

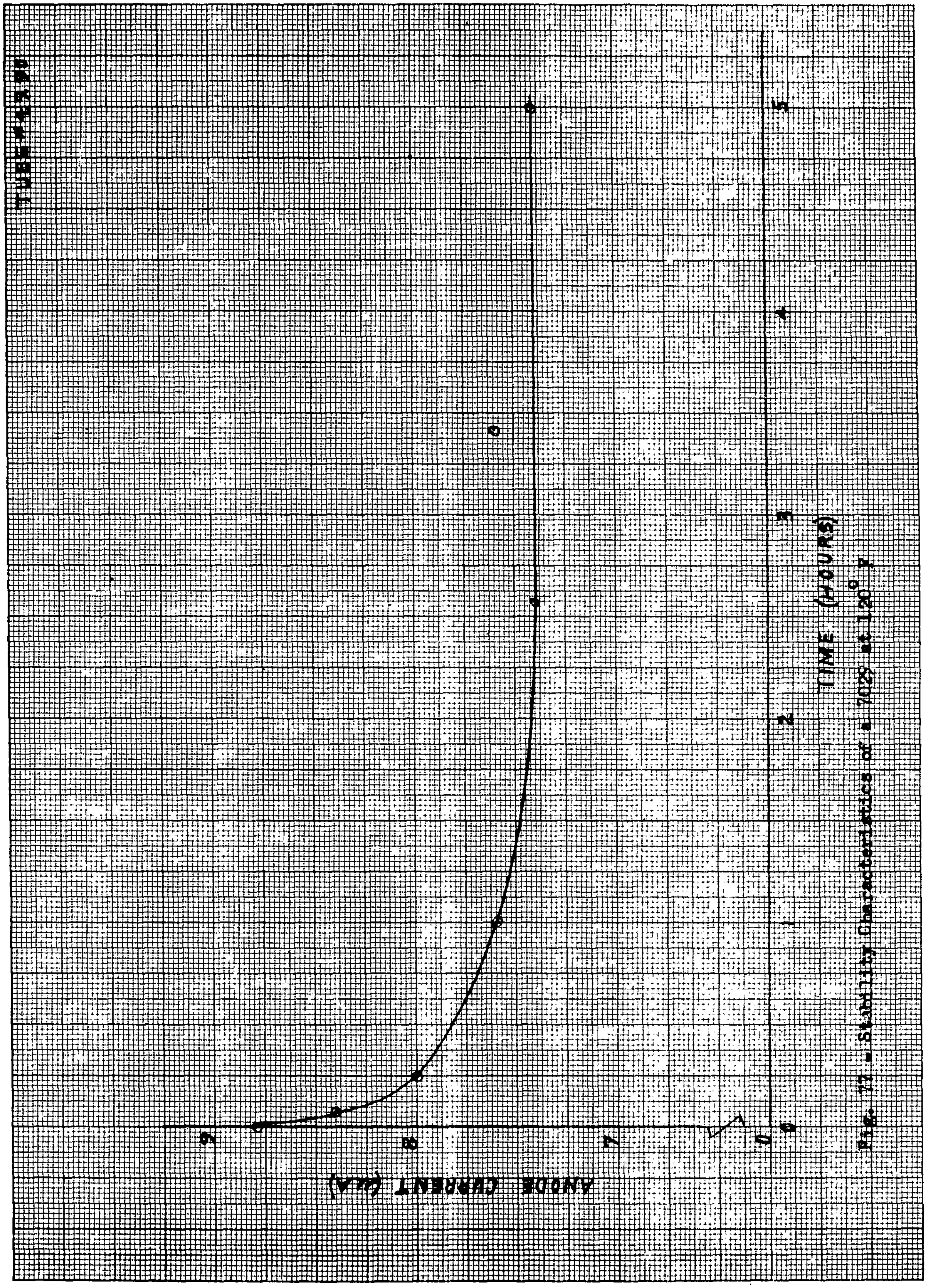


Fig. 71 - Stability Characteristics of a 7029 at 120° F

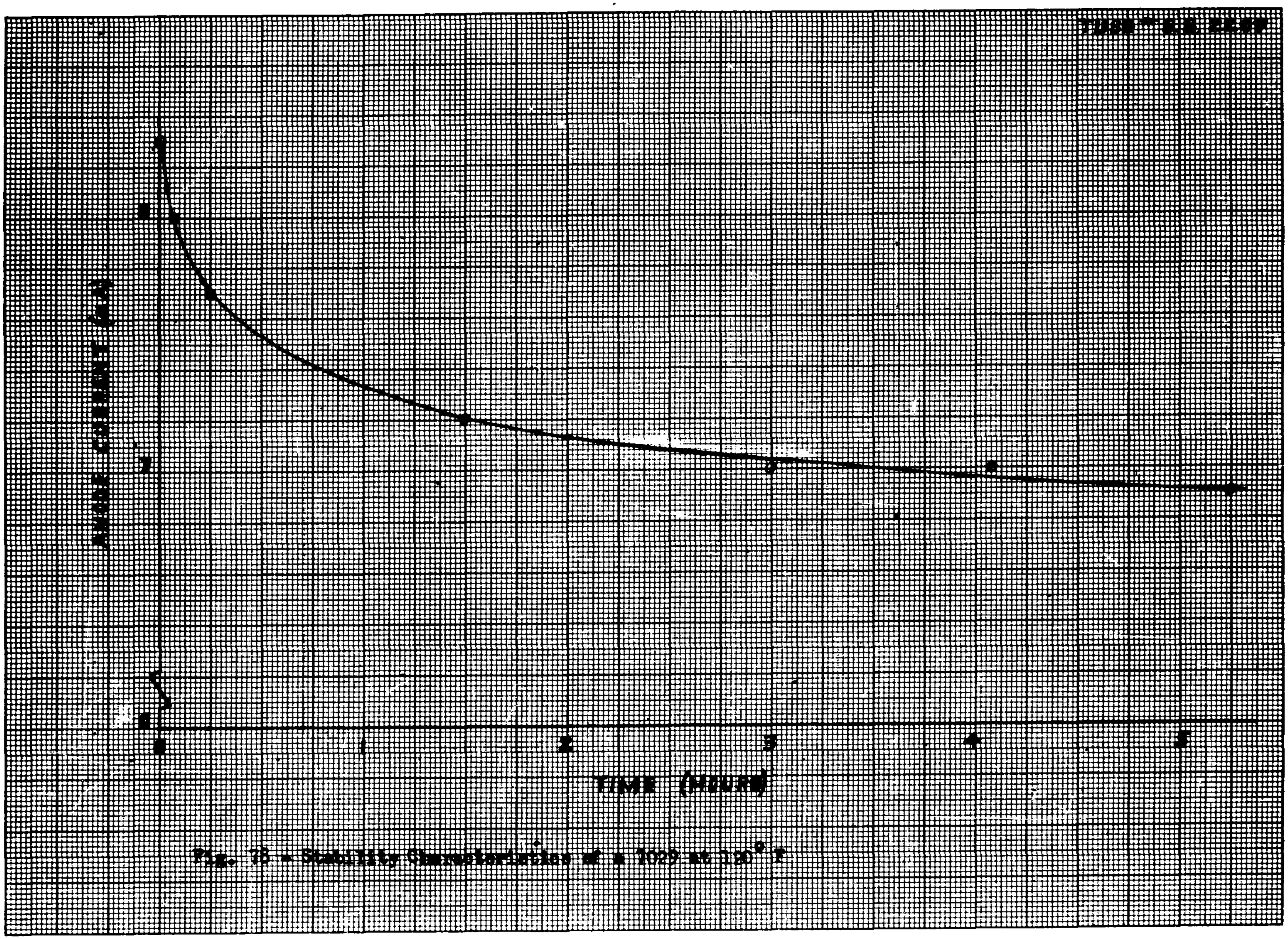


Fig. 78 - Stability Characteristics of a 7029 at 120° F

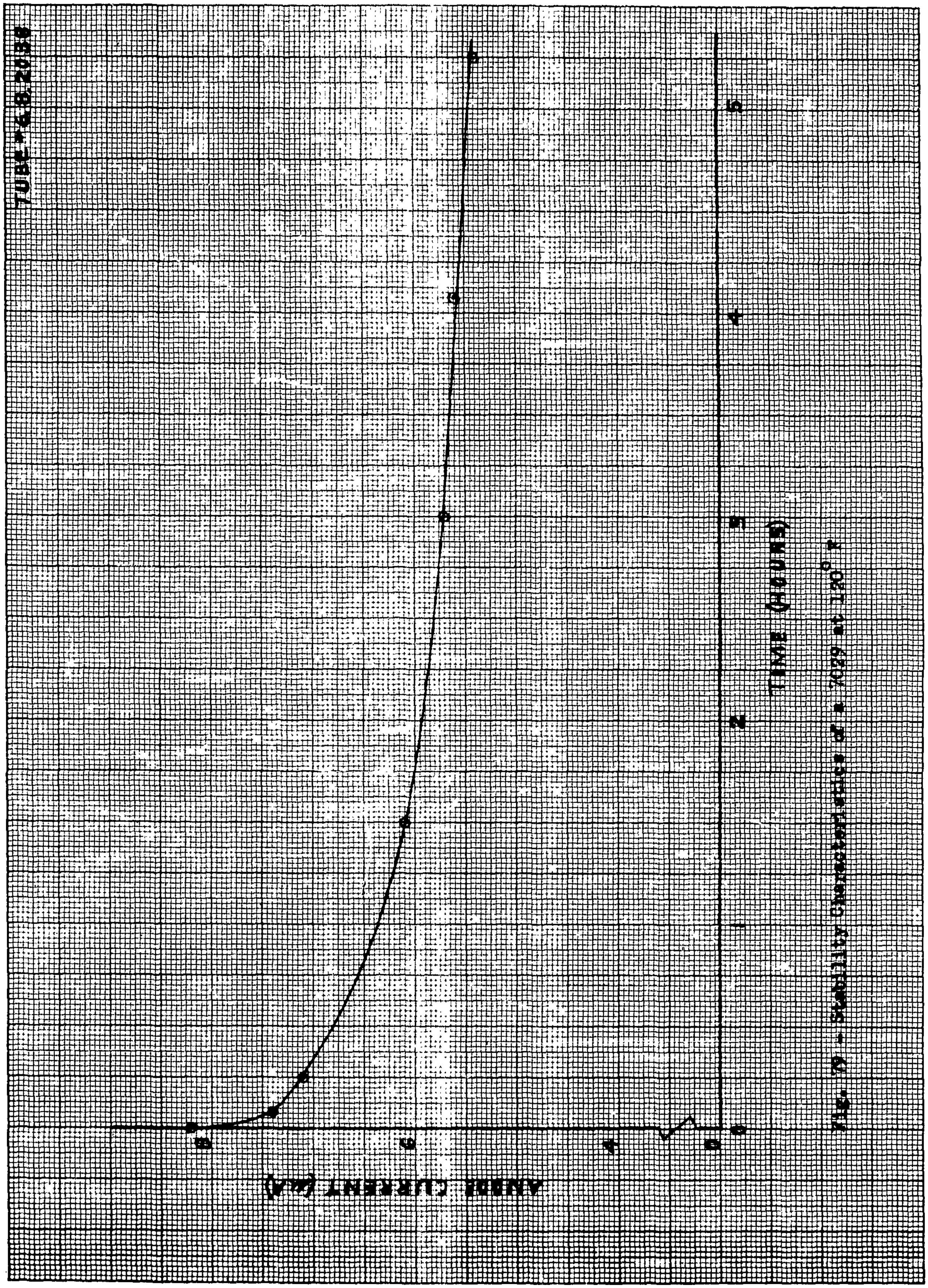


Fig. 79 - Stability Characteristics of a 7029 at 120° F

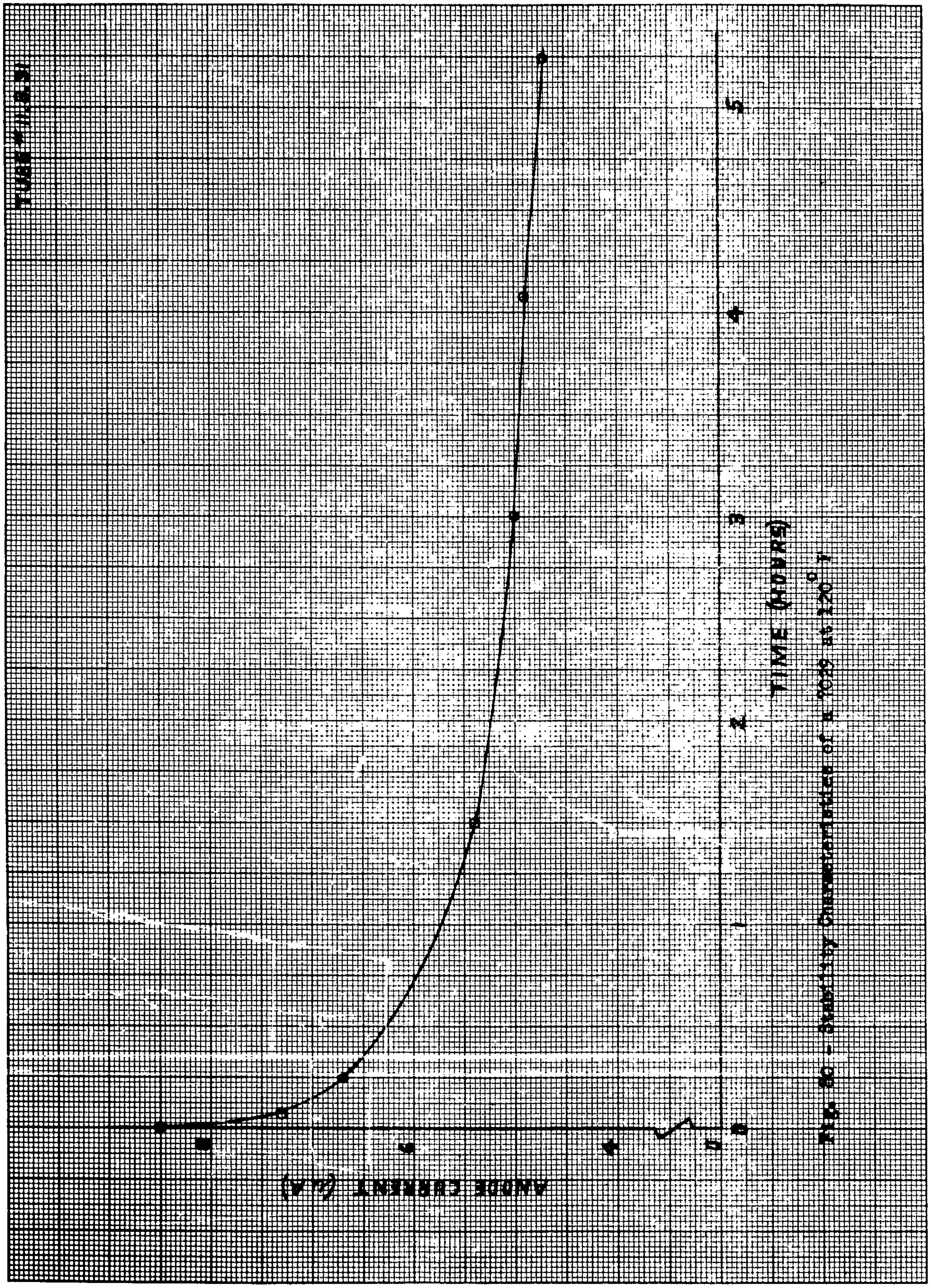


Fig. 80 - Stability Characteristics of a 7029 at 120° F

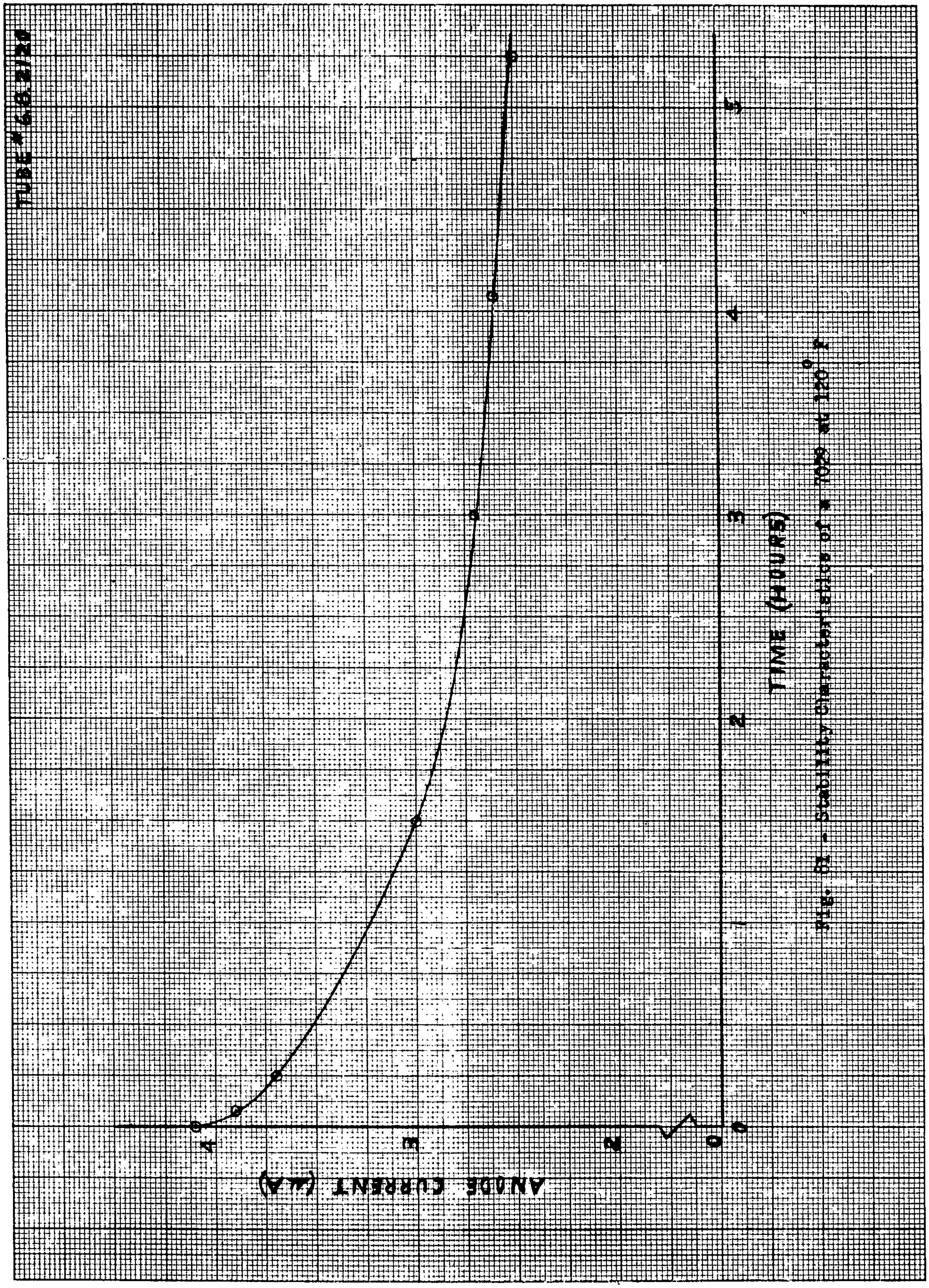


Fig. 81 - Stability Characteristics of a 7029 at 120° F

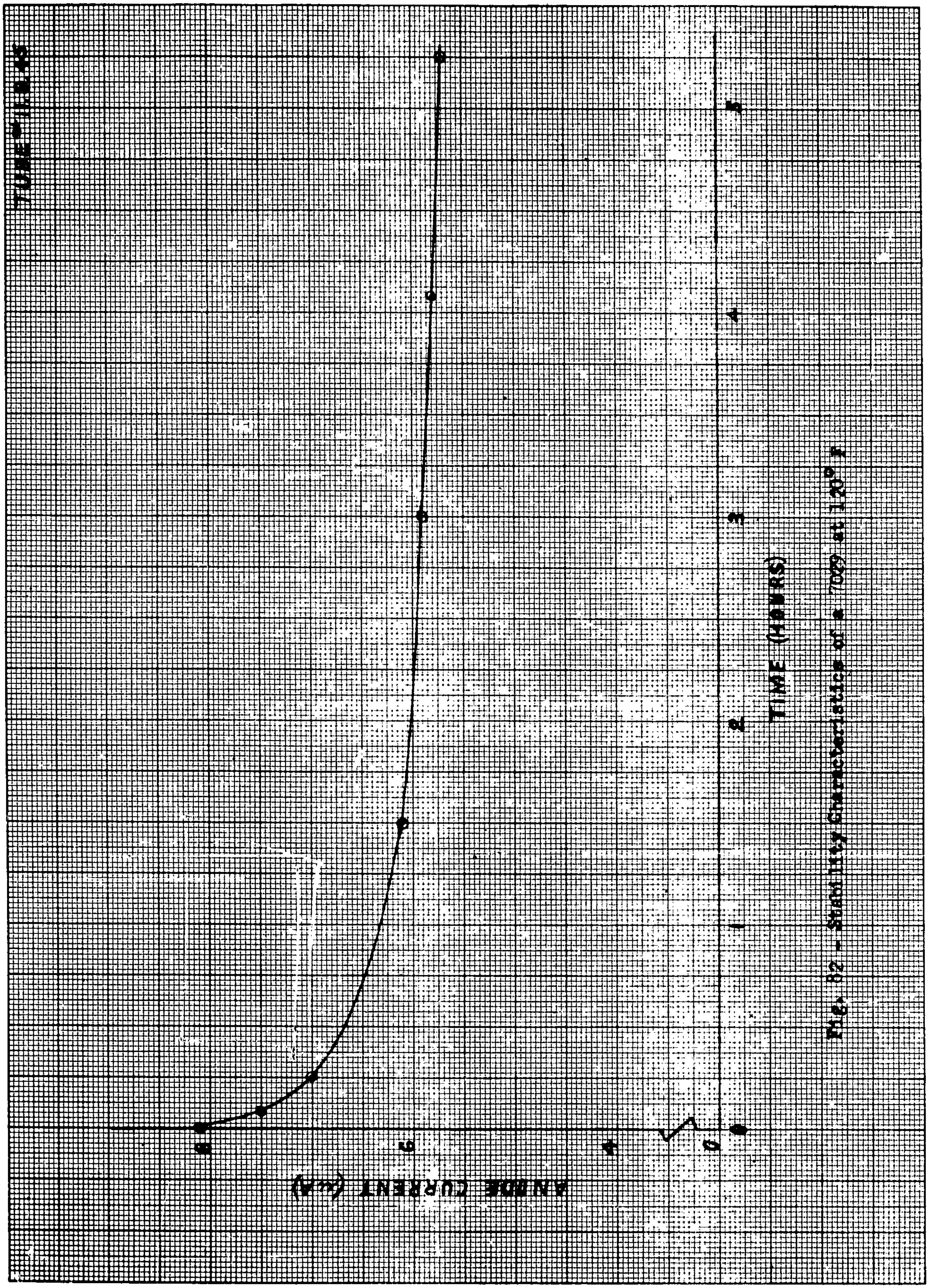


Fig. 82 - Stability Characteristics of a 7029 at 120° F

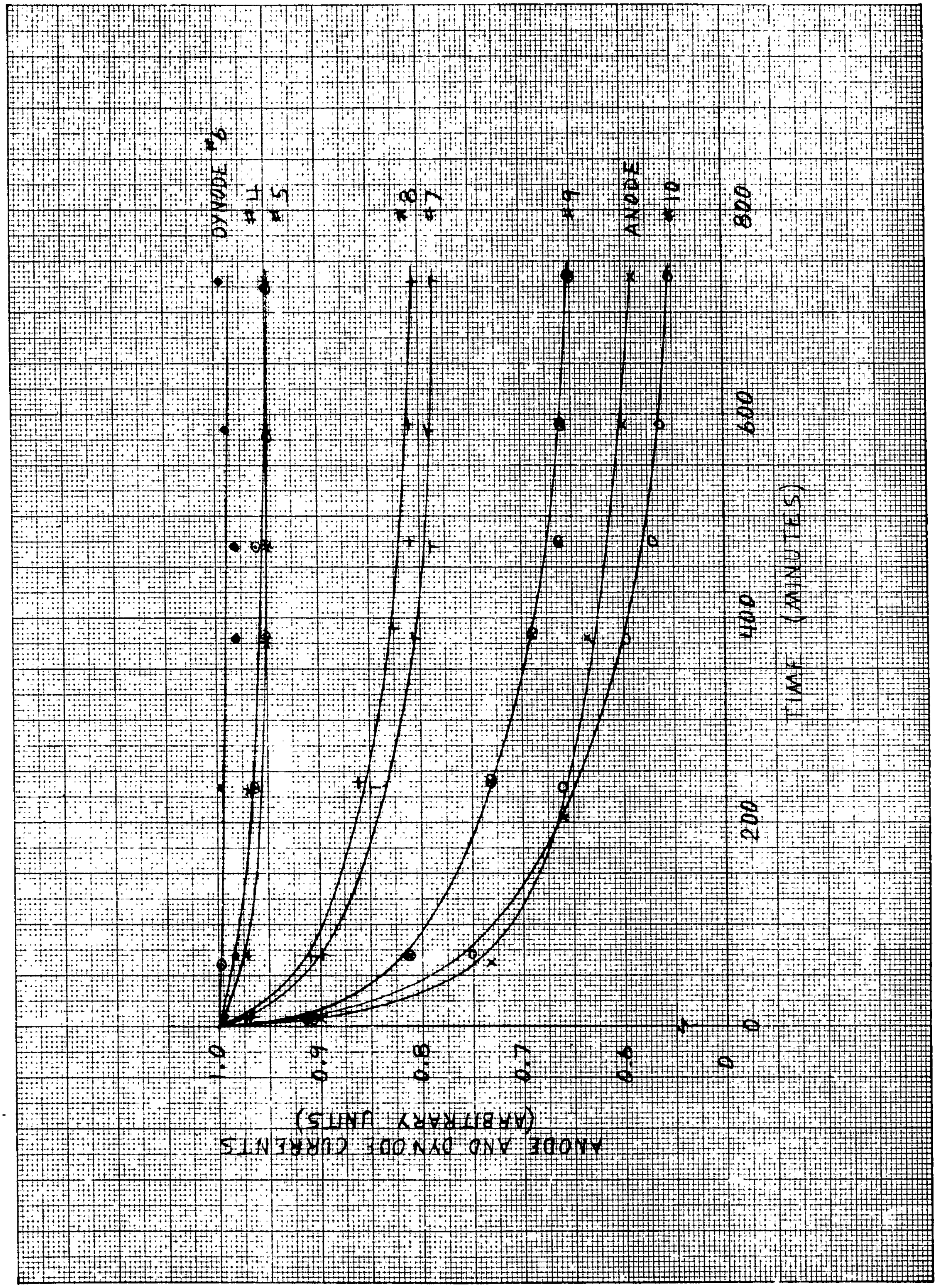


Fig. 83 - Stability of Anode and Dynode Currents of 7029 Photomultipliers

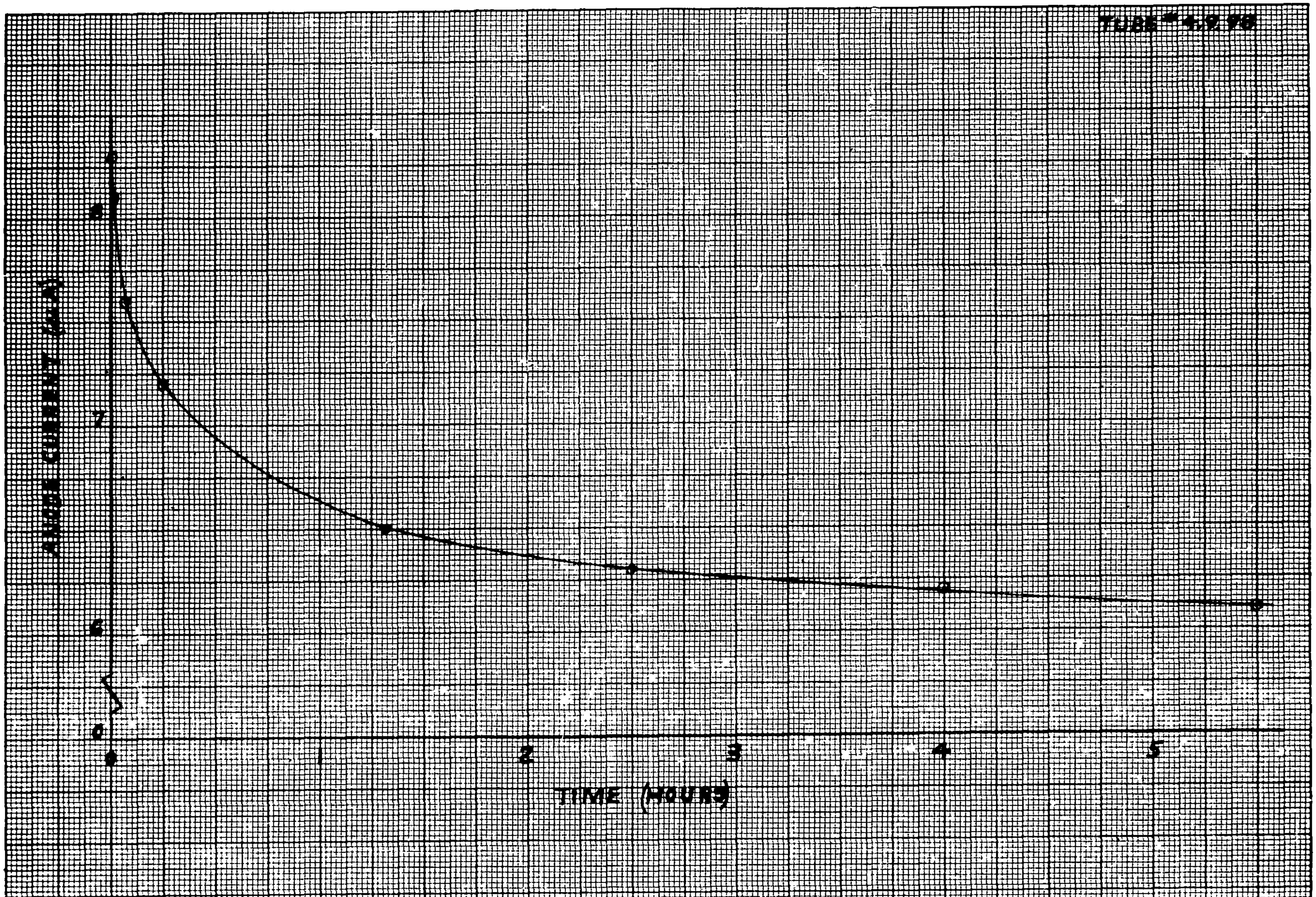


Fig. 84 - Stability Characteristics of a 7029 that was Differential Baked on Exhaust

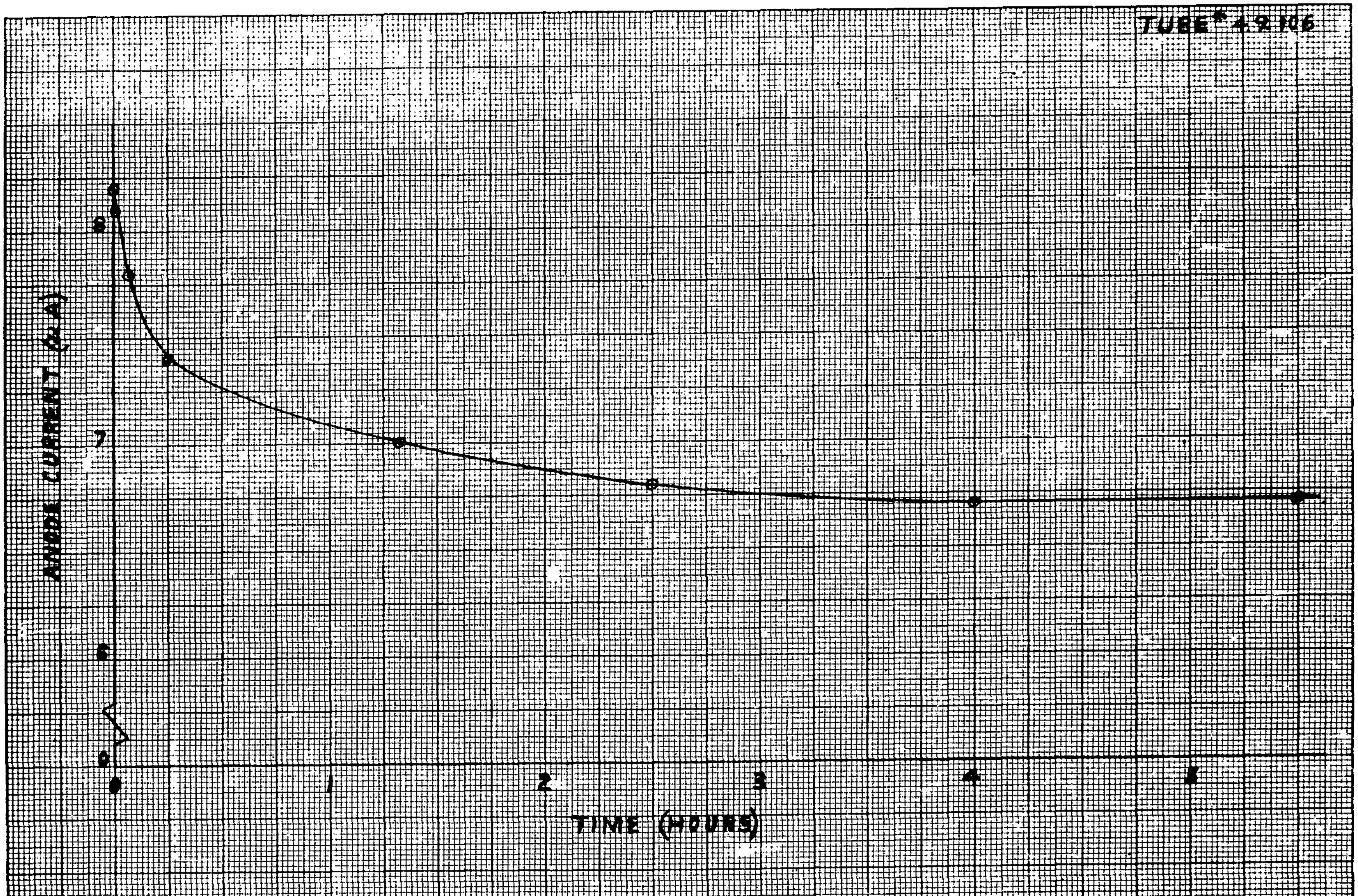


Fig. 85 - Stability Characteristics of a 7029 that was Differential Baked on Exhaust

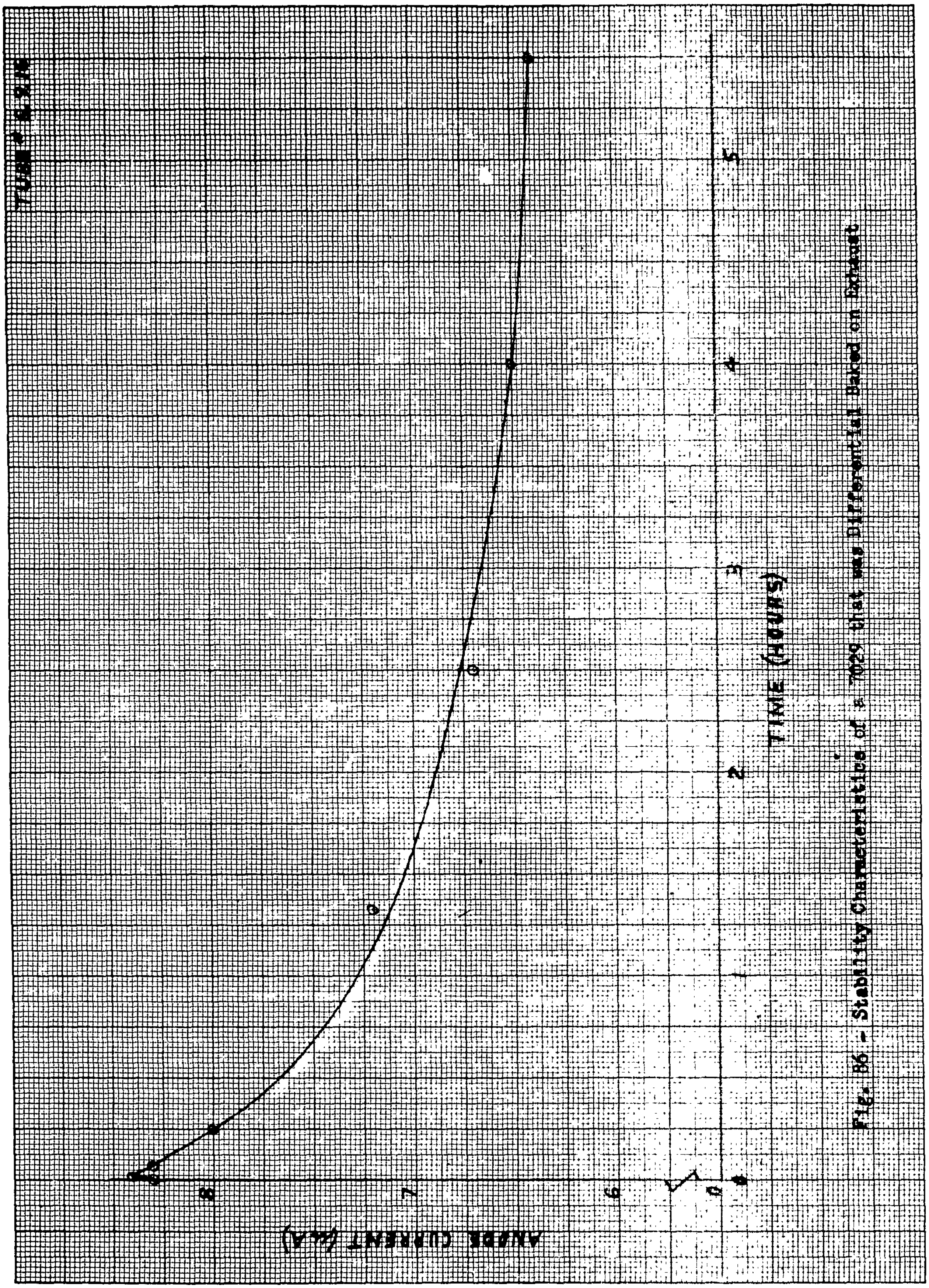


Fig. B6 - Stability Characteristics of a 7029 that was Differential Baked on Exhaust

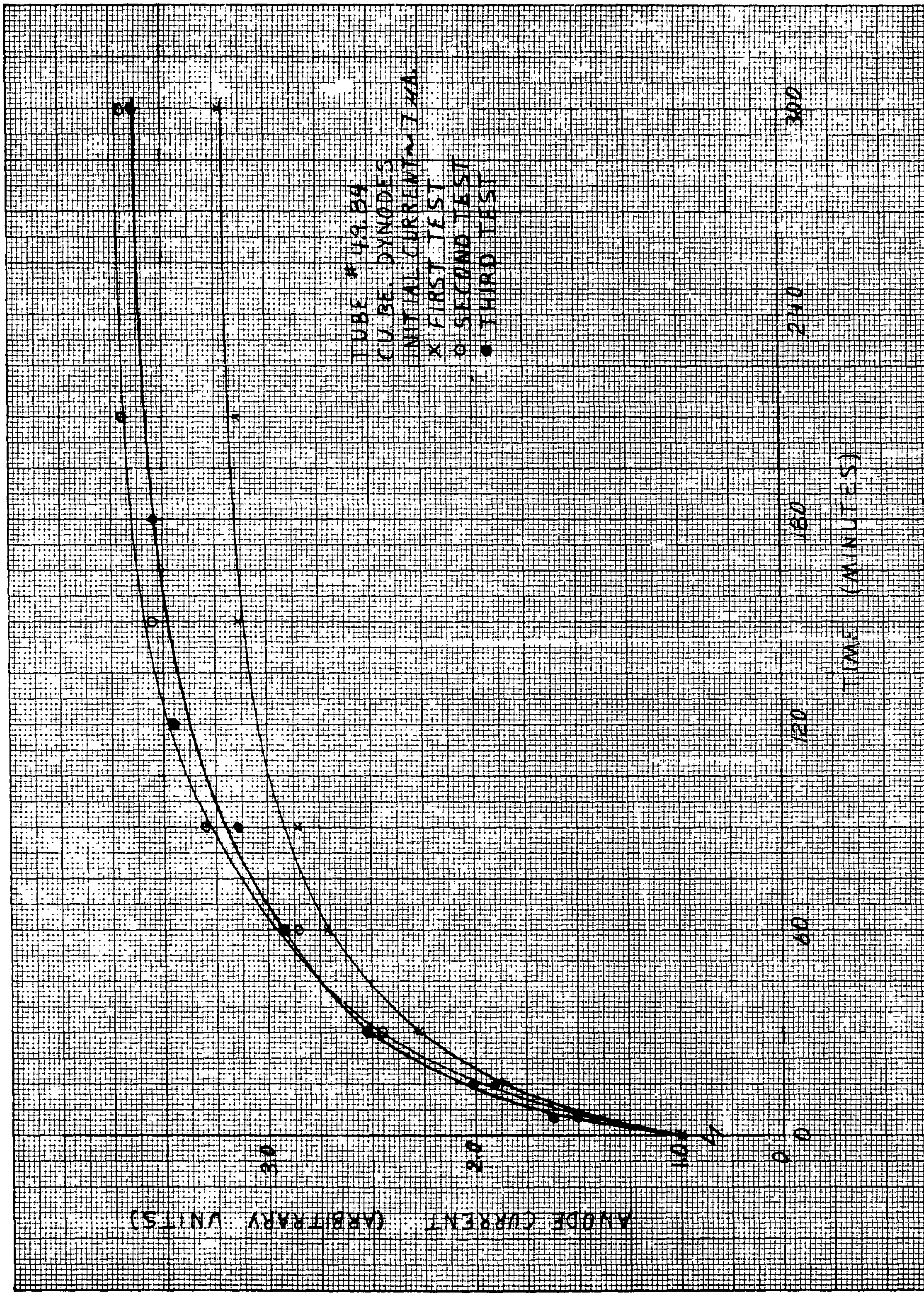


Fig. 87 - Stability Characteristics of a 7029 with CuBe Dynodes

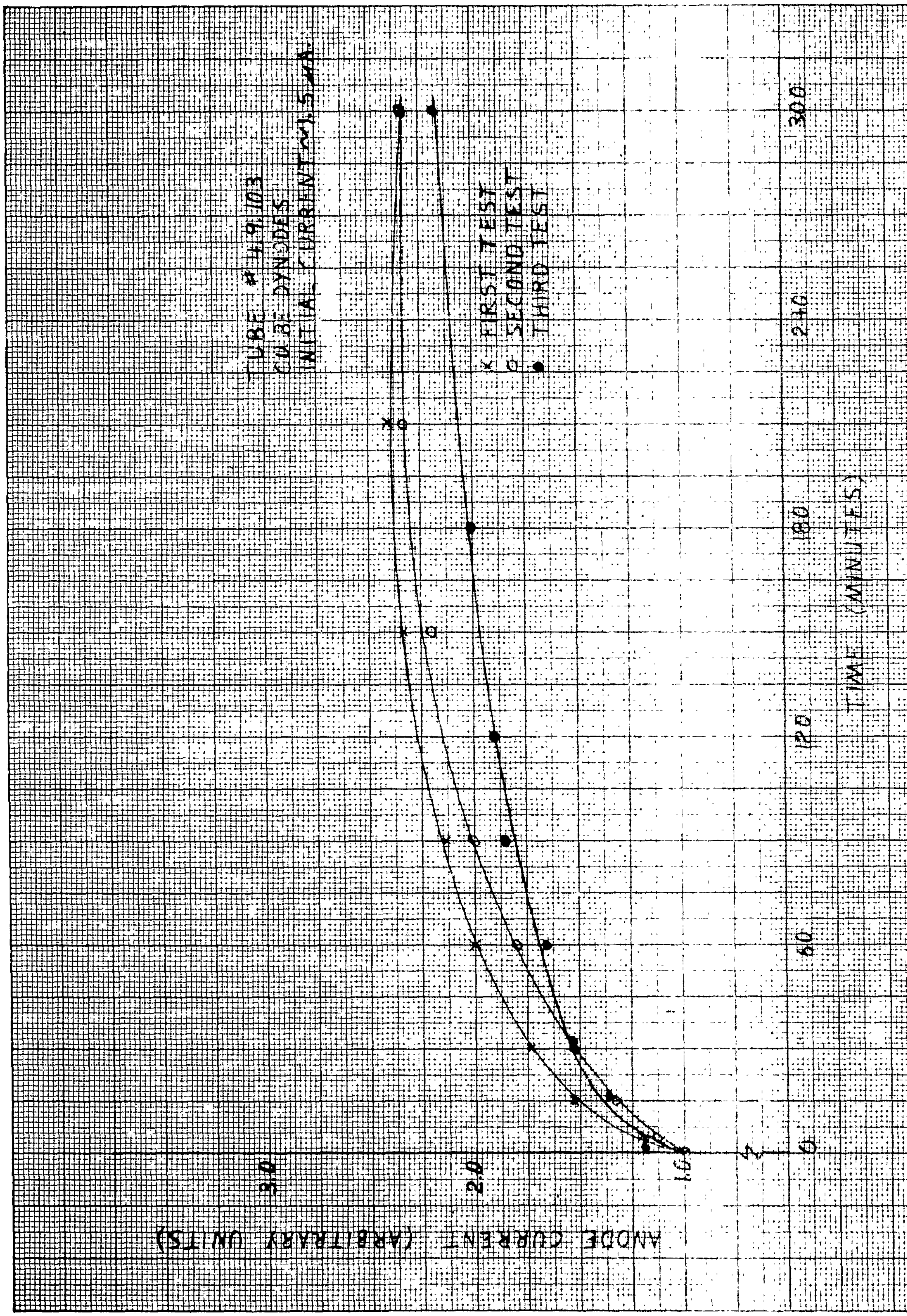


Fig. 88 - Stability Characteristics of a 7029 with CuBe Dynodes

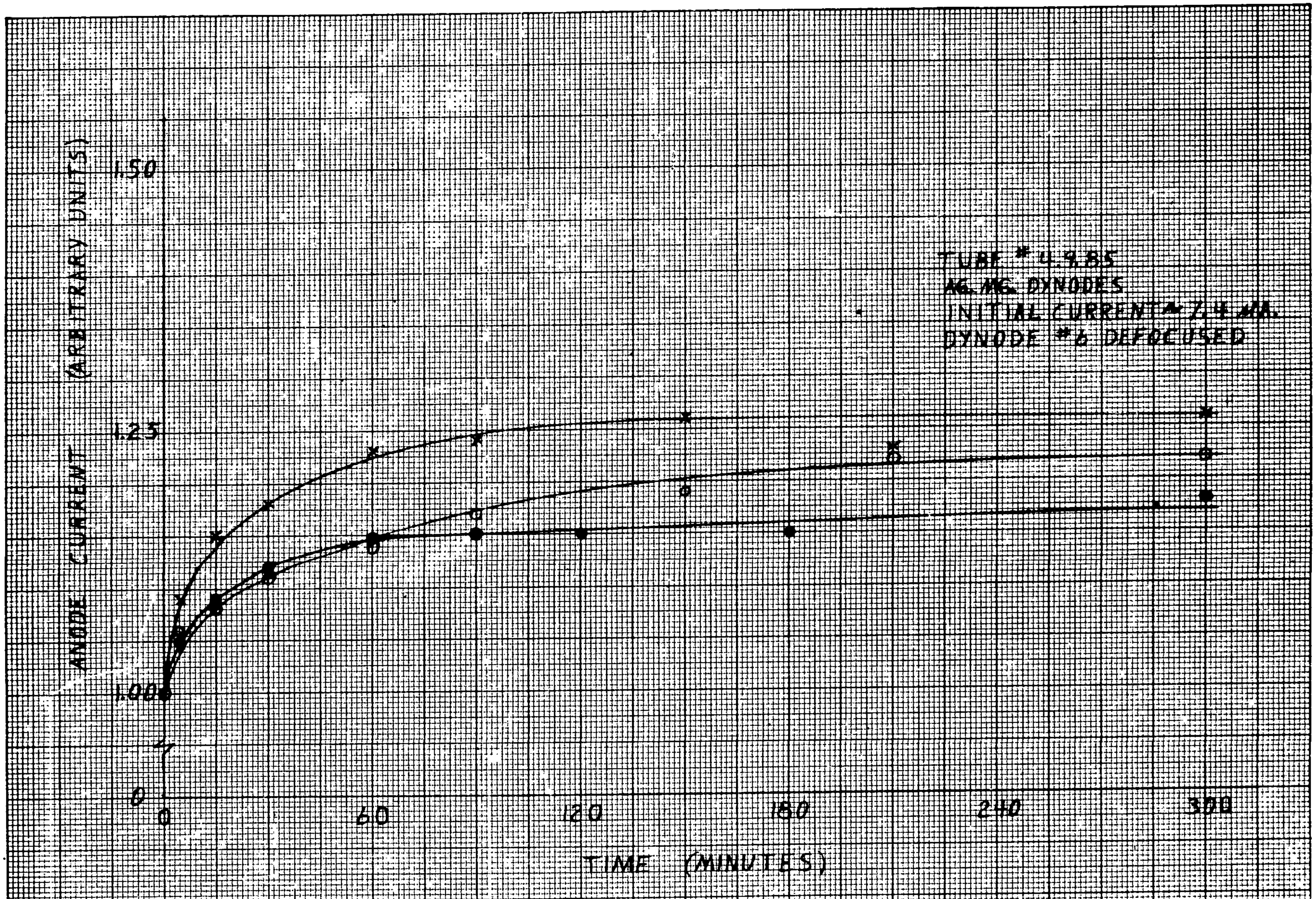


Fig. 89 - Stability Characteristics of a 7029 with AgMg Dynodes

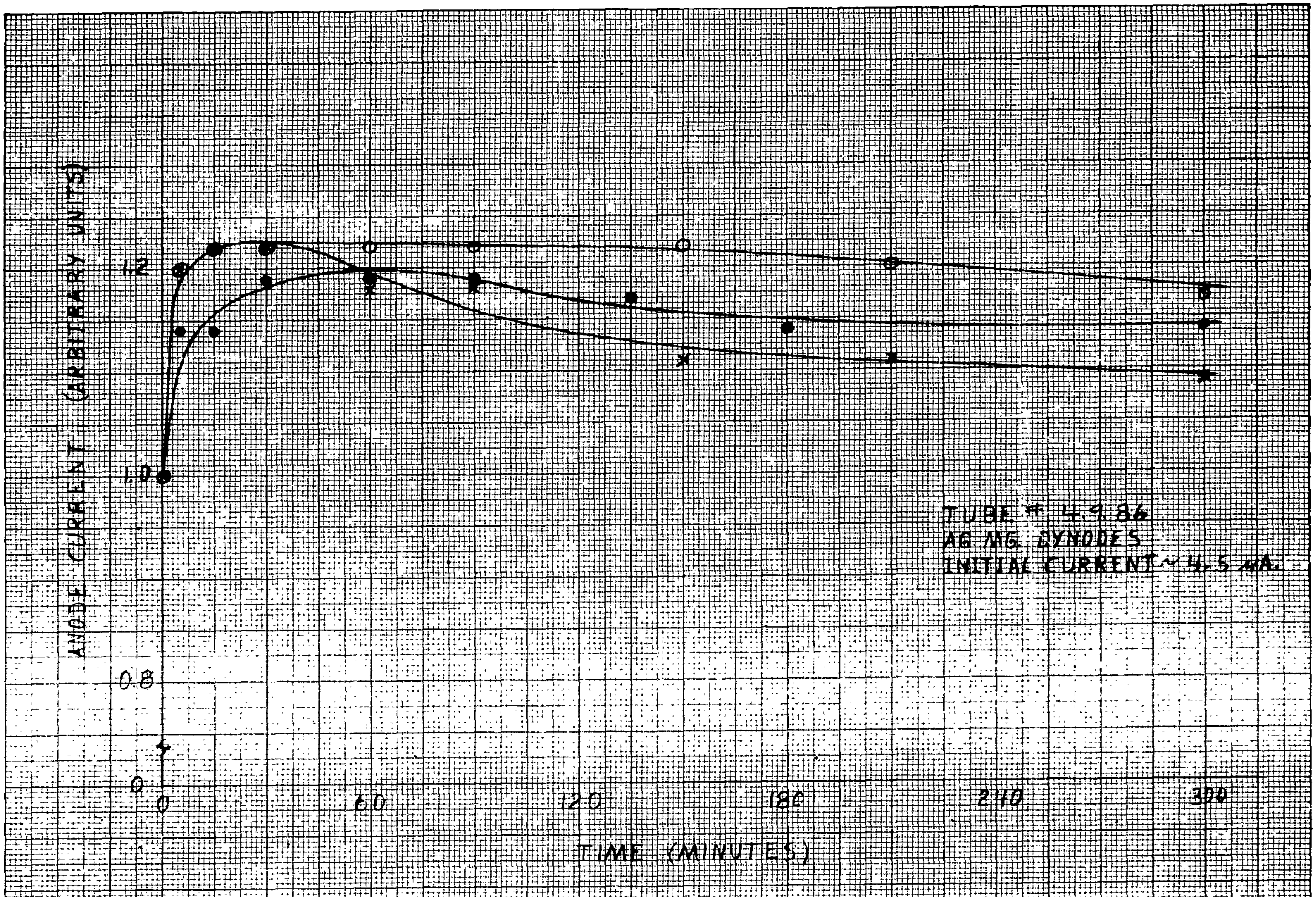


Fig. 90 - Stability Characteristics of a 7029 with AgMg Dynodes

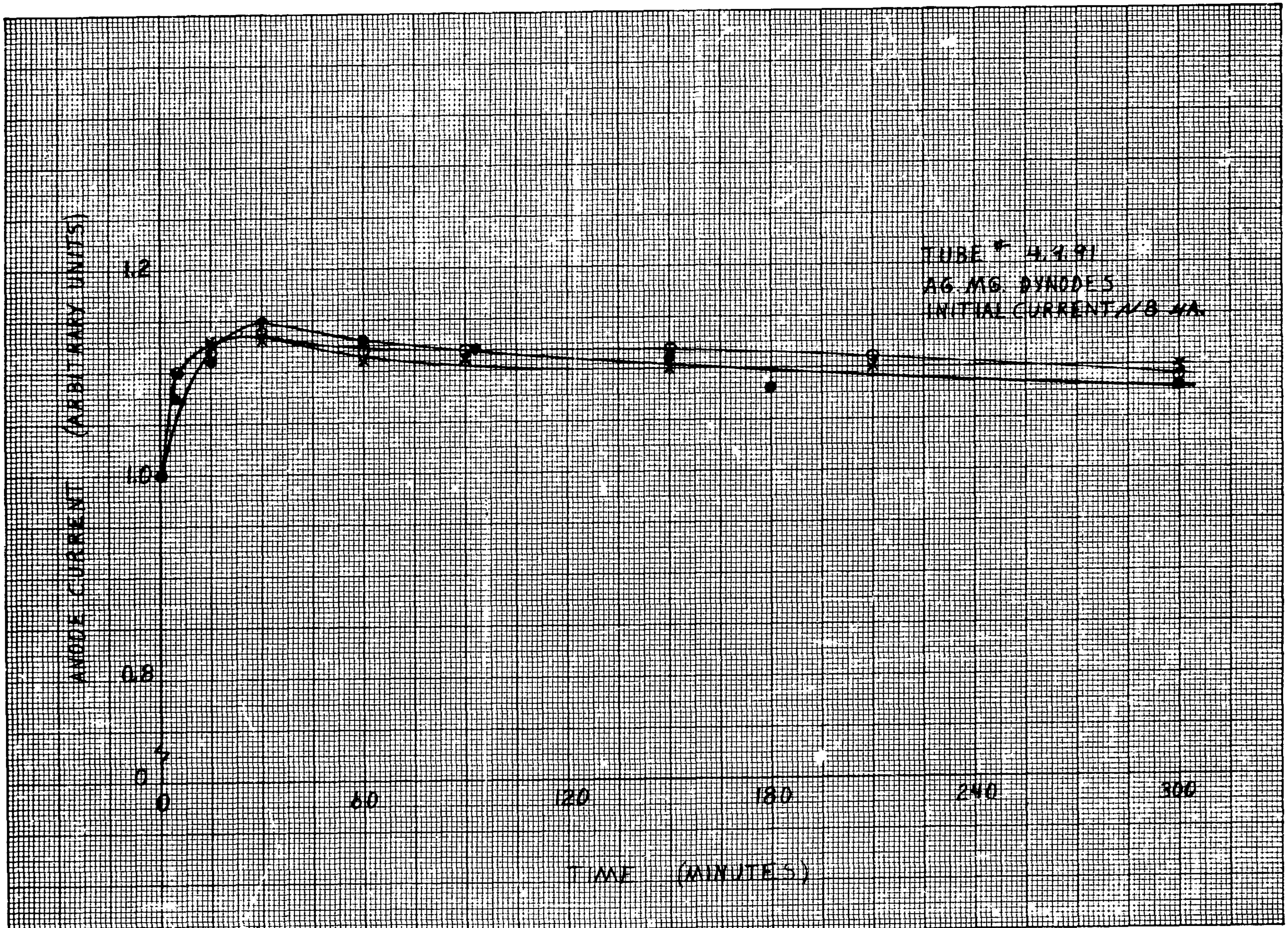


Fig. 91 - Stability Characteristics of a 7029 with AgMg Dynodes

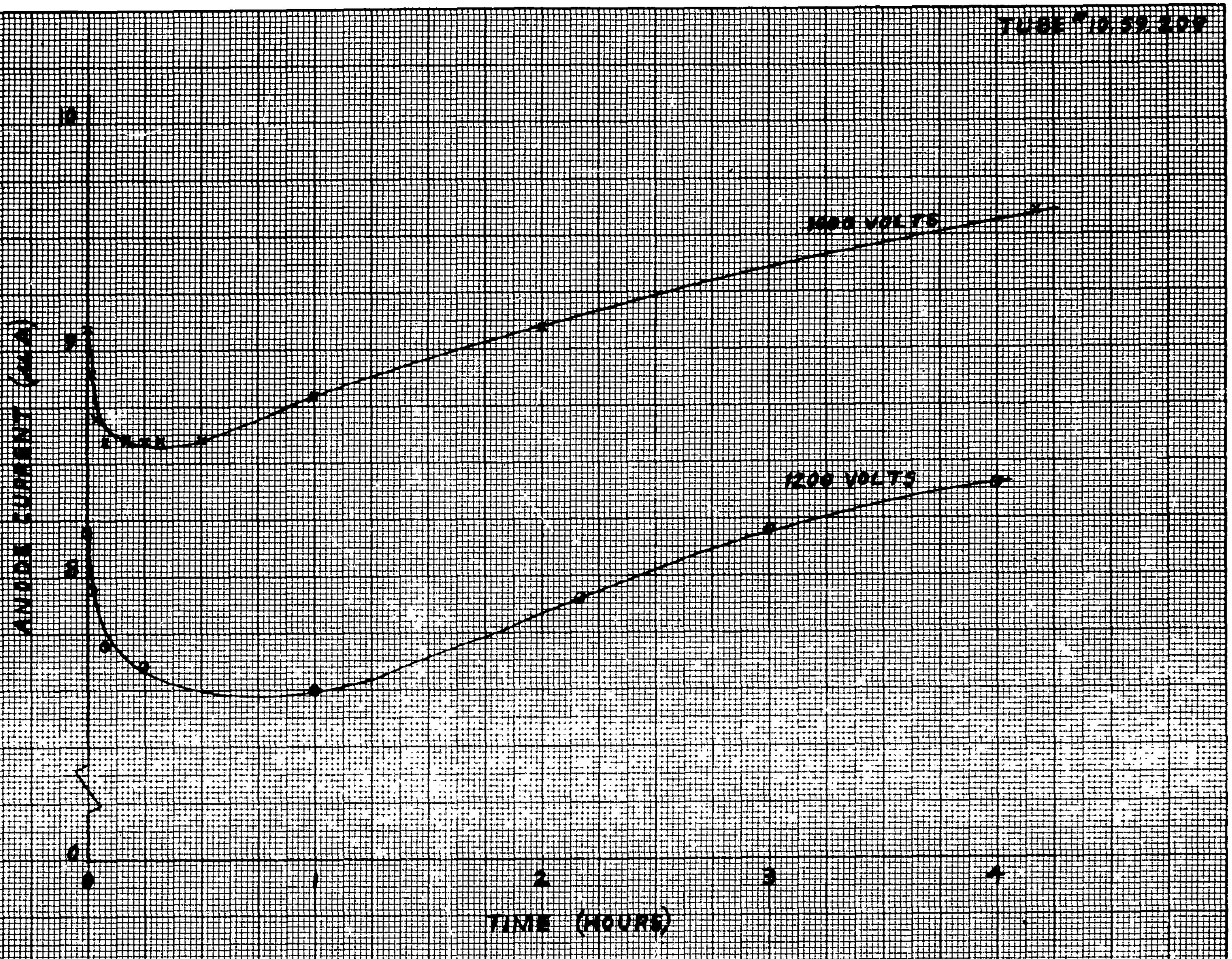


Fig. 92 - Stability Characteristics of a 7029 with Cs_3Sb Secondary Emitter Sufaces Formed on MgO Substrates

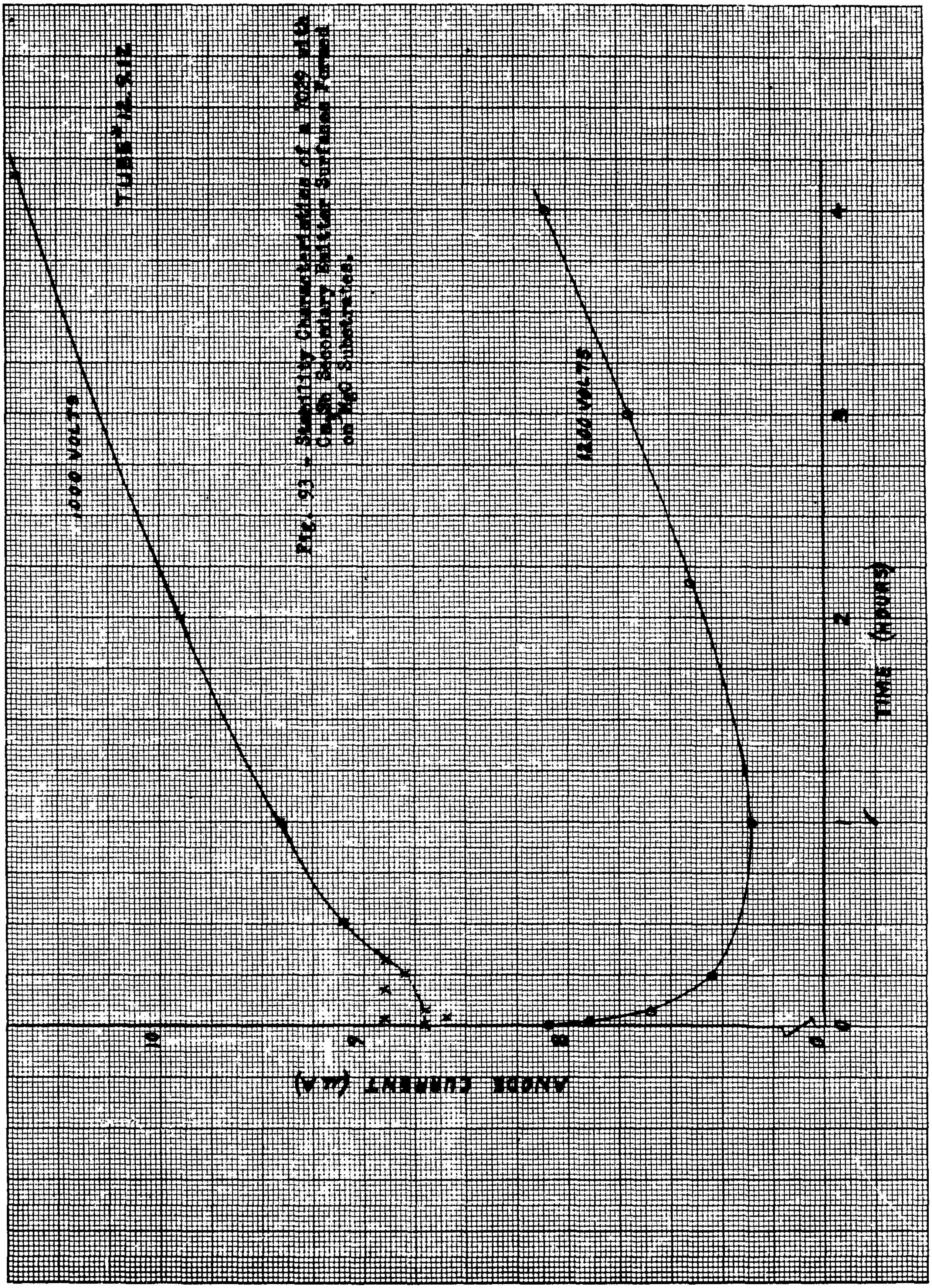


Fig. 93 - Stability Characteristics of a 7029 with Cs_3Sb Secondary Emitter Surfaces Formed on MgO Substrates.

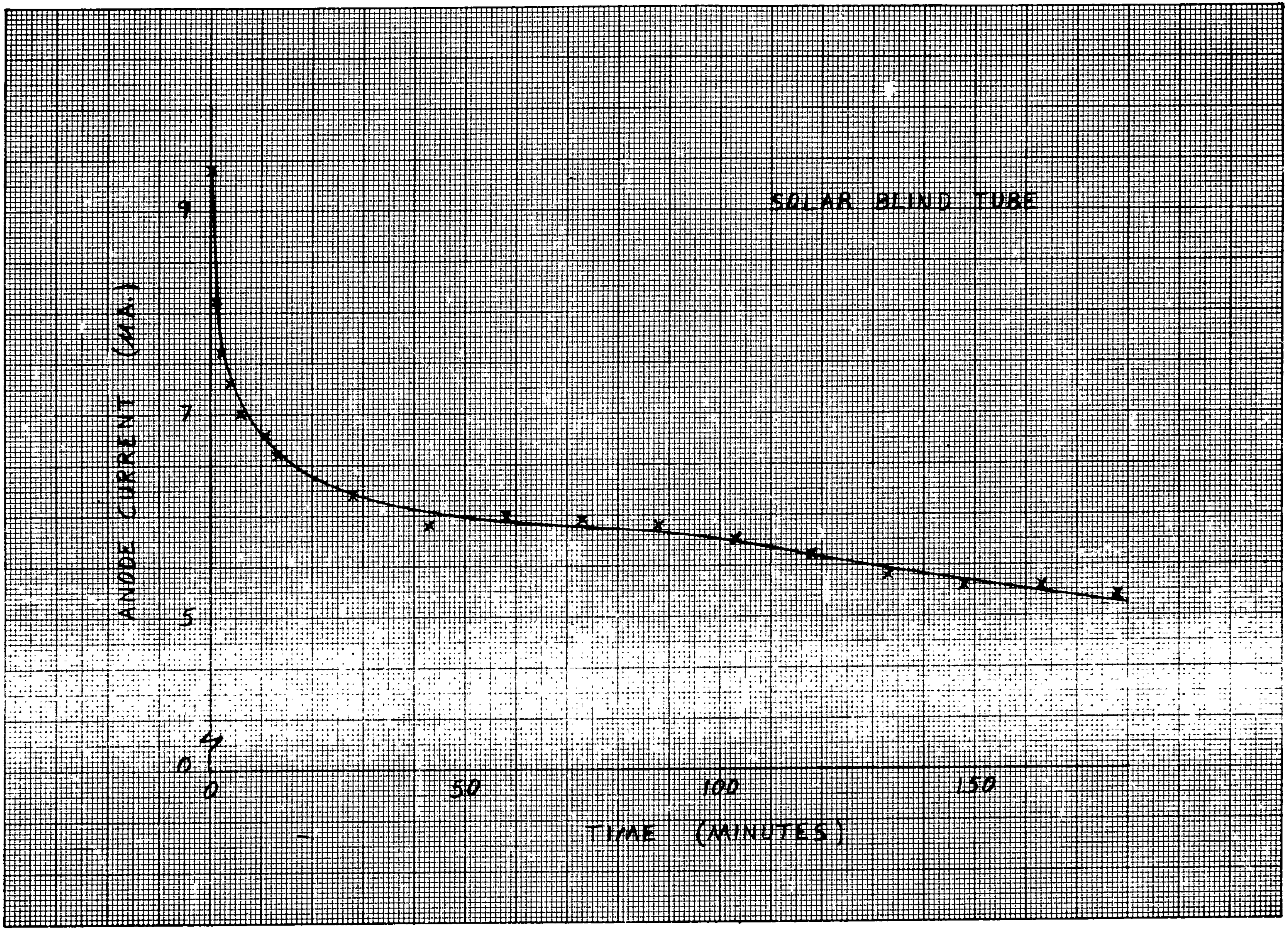


Fig. 96 - Stability Characteristics of a Solar Blind Tube with MgO

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